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IDENTIFICATION OF SPECIES OF FUSARIUM OCCURRING ON THE SWEET POTATO, IPOMOEA BATATAS

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INTRODUCTION

Students of the etiology of diseases caused by Fusarium are often handicapped by the fact that they get various results from what appears to be the same fungus and obtain like results from apparently different fungi. To throw light on the interpretation of such results and to serve as a guide for future studies, the group of Fusarium presented in this paper may be separated from the remainder of the genus.

Species of Fusarium play an important part in the diseases of *Ipomoea batatas* Poir., the sweet potato. Many of the 13 different species and varieties of this genus of fungi are more or less cosmopolitan and ubiquitous and seem to be harmless to the sweet potato but injurious to other plants. Other species, so far as known, are confined to this host and connected with serious troubles, such as the wilt disease and the dry-rot of the root. Owing to the heavy losses that plant industry suffers from these diseases, a thorough investigation was undertaken, in order to find methods for their control. This investigation, requiring an exhaustive study of the parasitic fungi, was handicapped by the fact that saprophytes are frequently associated with parasites and resemble them in certain stages so closely that they are readily mistaken for them. This led to contradictory reports as to the nature and causes of the diseases. The only way to get uniform results is to base these etiologic studies on a monograph of all the fungi associated with the diseases. This paper, although not exhaustive, includes at least the most important species of Fusarium occurring on the sweet potato. These have been grown in pure culture for almost two years until "criteria of the norm and sub-

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norm" could be found and a sufficient constancy of the spores obtained under constant conditions. The diagnoses based exclusively on pure cultures allow also a determination of the fungi from field material when the effect of different degrees of moisture and of various substrata is understood, when what is youth and what old age, and what is mature and what immature in species of Fusarium [1] are known.

METHOD OF DIFFERENTIATION

The genus Fusarium has a number of vegetative and spore stages,[2] and their so-called variability may be a source of confusion. This is evident from the fact that transfers of mycelium produce a growth quite different in general appearance from that derived from spores of the same fungus to the same medium under conditions otherwise identical. Conidia from the outside and mycelium from the fibrovascular bundles of a wilted plant isolated separately and grown and studied under the same conditions may show differences in general appearance and still be the same organism. They must be regarded as the same organism if one form can be transformed into the other. The following may be cited as proof: Hundreds of wheat grains among samples sent to the Kaiserlichen Biologischen Anstalt für Land- und Forstwirtschaft, at Dahlem, near Berlin, Germany, to determine the cause of poor germination, showed carmine-red spots of fungous mycelium. Numerous cultures, derived from epiphytic and endophytic mycelium of different seeds, yielded a number of fungi, such as Verticillium, Spicaria, Alternaria, Trichothecium, Langloisula, Ramularia, Melanospora, Leptosphaeria, Helminthosporium, Gibberella, and Fusarium (three species), without an ascus stage.

The four last-named organisms, afterwards found to be distinct, showed practically the same general appearance; as, for example, in a sterile cottony growth of aerial mycelium all four showed yellow on sterilized rice media and carmine red on steamed potato. Repeated transfers of mycelium to the same medium did not give differential characters sufficient to identify any one character by this method. In some cases a few small conidia scattered in the mycelium were developed, but without any constant shape that was characteristic. Within a month, however, some plectenchymatic bodies appeared, often only one or two (in a test-tube culture on potato) pushing through the sterile mycelium. Later, an erubescent to orange color appeared in one culture and an ochreous brown color in another, especially when exposed to daylight. This difference gave the first striking contrast between

[1] Exsiccatæ will be prepared from all of these fungi and, when completed, subcultures of the original strains will be sent to any-one interested.

[2] Such expressions as "mycelial stage," "sclerotial stage," "sporodochial stage," "pionnotes stage," "micro-conidial stage," etc., for the sake of convenience, are used quite generally throughout this article. While they are not to be regarded as true stages in the accepted sense of the word, they are particularly desirable terms to use in connection with a taxonomic study from pure cultures of the genus Fusarium. For definition of terms see Wollenweber, H. W. (1913c).

these species. The spore colors were emphasized through the contrast with the carmine mycelium thallus common to all four strains. These ochreous and orange spots contained masses of characteristic sickle-shaped conidia. One culture was found to have ochreous spore masses of the type illustrated in Plate XVI, fig. *J*, although the majority of cultures contained spores of a longer type (Pl. XVI, fig. *O*). Cultures with orange conidial beds, however, presented a quite different type from both of those just mentioned. This type, although not figured, was more subulate than the forms in Plate XVI, fig. *M*. A second orange type in another culture was of the same general shape, but a little broader. (See Pl. XVI, fig. *G*.) The descendants of single spores of these four types of sickle-shaped conidia, repeatedly transferred to different vegetables, stems, heads, and grains, remained distinct from each other, but constant in themselves in the same spore stage. The sporodochia were formed more freely in subcultures, especially on stems. In addition to this so-called tuberculariа-like sporodochial stage, one of the four strains (Pl. XVI, fig. *O*) produced perithecia and was identified as *Gibberella Saubinetii* (Mont.) Sacc. It had no chlamydospores, but thick-walled swollen cells occurred in plectenchymatic bodies (stroma) and in closely interwoven hyphæ (Pl. XIV, fig. *J*), which often resembled chains of chlamydospores, but differed from them in function. The other similar type (Pl. XVI, fig. *J*) never formed perithecia, but produced clusters of chlamydospores. The latter were quite as resistant as perithecia and have proved to be an effective resting stage in species destitute of the ascigerous form. Later, the two other strains of the section Roseum with orange conidia were also found to differ more than was apparent at first glance. The broader type produced blue globose sclerotia in cultures on stems repeatedly watered when dried out. These bodies resembled in general appearance perithecia of Gibberella, but were massed and much smaller, 56 to 70μ in diameter, and without any indication of asci. Such sclerotia were entirely wanting in the species having the slender type of conidia. The study for some years of these four above-described strains isolated from wheat (*Triticum* spp.) did not change the previous conclusion that they were four separate fungi: *Gibberella Saubinetii* (Mont.) Sacc. (Pl. XIV, and Pl. XVI, fig. *O*); *Fusarium culmorum* (W. G. Sm.) Sacc. (Pl. XVI, fig. *J*); *F. subulatum* App. and Wollenw.; and *F. metachroum* App. and Wollenw. These fungi were formerly included in the collective species *F. roseum* Link autorum.

From this example it is seen that to differentiate these fungi is only a question of method. A skeptic, however, may ask, Why is *Fusarium culmorum* not the conidial stage of Gibberella? It must be conceded that the conidia derived from ascospores of Gibberella resemble in shape those of *F. culmorum* (Pl. XVI, figs. *J* and *O*). It would not be convincing to state that *F. culmorum* has 5-septate conidia with a maximum

length of 45μ and an average breadth of 7μ, while the Gibberella-Fusarium has 3 to 5 septate conidia, the quinqueseptate ones being up to 60μ long and 5.5μ broad, since isolations of both, which have been repeatedly made, from different hosts showed a range of variation in the size of conidia in different strains of the same fungus. For instance, *F. culmorum* from Irish potato (*Solanum tuberosum*) attained only an average diameter of 6μ, and another strain only 6.5μ, instead of 7μ, as in the original strain from Irish potato. Strains from sweet potato and wheat often gave a smaller maximum. On the other hand, strains of Gibberella-Fusarium already studied from wheat, Irish potato seed balls, sweet potato, and stalks of maize reach an average maximum of 6μ, though in general not exceeding 5.5μ. The septation also varies a little in different strains from the same and from different hosts. The facts fully justify skepticism as to a separation of *F. culmorum* and the Gibberella-Fusarium.

However, a constant difference between the *Fusarium culmorum* and the Gibberella series has been discovered. Chlamydospore clusters, which are absolutely wanting in Gibberella, occur in all strains of *F. culmorum*. This means that the ascigerous fungus, having perithecia, has therefore no longer any need of chlamydospores and may have lost this stage. If the formation of perithecia has been prevented, the effused plectenchyma (Pl. XIV, fig. *J*), which also represents the base of the stroma, may function as a secondary overwintering stage. *F. culmorum*, on the contrary, is dependent on chlamydospores if the conidia die from unfavorable conditions. Finally, the conidial stage itself, generally reduced in Gibberella, is highly developed in *F. culmorum*, forming great masses of conidia in sporodochia and in pionnotes. That the conidia of Gibberella are less independent than in the other species is evident from the fact that earlier or later they join by their anastomosing germ tubes and simply serve as a basis for the ascigerous stroma, thus practically losing their existence as a conidial stage. In *F. culmorum*, on the other hand, conidia have been found to be perennial and resistant for years, and, besides, are able to produce chlamydospores from their cells if they are overwatered or exposed to other unfavorable conditions.

Summarizing these results, it is seen that there is no good reason for regarding *Fusarium culmorum*, a representative of the section Discolor, as the conidial stage of Gibberella. Neither can *F. subulatum* and *F. metachroum* be a stage of this ascomycete, since they have conidia characteristic of the section Roseum (Pl. XVI, fig. *G*). This section is often confused with Gibberella, owing to the frequent association of the so-called *F. roseum* Link with Gibberella on grains of cereals, while the true Fusarium of Gibberella is comparatively rare in nature because of its ready metamorphosis into a stroma.

If doubts based only on unproved analogical conclusions suggested by certain relationships in shape and color of single stages are disregarded and the results of pure cultures in comparison with the same organism

grown under natural conditions in the open field are considered, it must be conceded that the taxonomy of these fungi can be based on studies of pure cultures in a normal condition, even when it is impracticable to make comparison with material from nature.

Fungi from nature also contain a great many abnormal stages. It is often very difficult to determine whether the material in hand is normal. As to what is normal or what is different from the rule depends in the end on the personal judgment of the investigator.

Before proceeding to a general discussion of the "Criteria of the norm" it may be stated that the investigations of the problem have shown that species of Fusarium, with and without the perfect form, make a normal growth in artificial media. In other words, pure cultures afford an efficient and convenient basis for taxonomic and pathological studies. Sterilized plant stems give a "mean proportional" of nutrition on which are developed the most characteristic stages without loss of vital power.

CRITERIA OF THE NORM

A great variety of conditions are found in pure cultures, especially when different media are used, from which it is always necessary to select some and reject others. Although sterilized plant stems gave ordinarily a good growth, the shape, septation, and relative viability of the conidia depended largely on the quantity of water present in the culture, whether grown in light or darkness, whether transferred from agar or gelatin containing strong acids or alkalis, etc. For instance, in *Gibberella Saubinetii* the cells of spores become barrel-shaped from the imbibition of water (Pl. XIV, figs. *H* and *K*, 2) when septate conidia are transferred from a concentrated to a dilute medium.

If, however, the conidia are dried out, a constriction takes place instead, with the result that the septa project ringlike (Pl. XIV, fig. *F*, seventh spore). Under similar influences the ascospores react in the same manner, the cells become swollen (Pl. XIV, fig. *E*, 1), constricted (Pl. XIV, fig. *E*, 3), or remain unchanged (Pl. XIV, fig. *E*, 2). Such reactions, although more striking in the living cells, are not confined to them, but may occur also in killed cells. Vacuoles are often formed in swollen cells, in mature chlamydospores (Pl. XIII, fig. *D*), conidia (Pl. XIV, fig. *H*), in plectenchymata (Pl. XIV, fig. *J*), and in overwatered hyphæ. Vacuoles may occur also in unswollen cells (Pl. XVI, fig. *H*). With some exceptions, such as in chlamydospores and plectenchymata, the production of vacuoles is rarely a characteristic of health and longevity, so that it is of doubtful value for the norm, especially when associated with swellings.

There is a stage, however, which is characterized by neither swollen nor constricted cells that occurs in conidia, ascospores, hyphæ, and more or less in other organs of fungi. From a long experience it may be said that this stage has the highest constancy in average size, curvature,

septation, color, and is further characterized by longevity. Therefore, this stage and all conditions favoring its production may be called the normal stage.

The reliability of the taxonomic work on the Fusarium problem depends, therefore, on the reliability of this criterion of the norm on which the results are based. If we rely on this test, attention must be given to diagnoses based on other criteria of the norm. Many descriptions doubtless include the measurements of swollen and constricted stages of conidia and ascospores and consequently show a much higher range of variation. The average size, of course, gives a smaller range of variation than the absolute size of particular spores. The difficulty is further increased by the fact that the average size can not be based on an average of spores produced on agar, or from a single culture grown on stems, etc., for the reason that constant temperature, light, moisture, and atmospheric humidity can not always be produced. Even though all these environmental factors are constant, variation in the shape and the size of the conidia might result in subcultures by the transfer of a different type of spore. Inconstant environmental and other factors must be expected both in nature and in culture. If the shape, the septation, and the color of the spore are more constant under some conditions than under others, this state may be regarded as normal, the swelling and constriction of spores as abnormal.

An example: One conidium of Gibberella was 9-septate and 100 by 6μ in size; another which was 9-septate and with swollen cells measured 85 by 8μ, a third which was 2-septate measured 10 by 2.5μ. These would give a range of variation as follows: 2- to 9-septate conidia, 10 to 100 by 2.3 to 8μ. The average of so-called normal spores was 3- to 5-septate, 30 to 60 by 4.25 to 5.5μ.

According to Saccardo (1879, p. 513)[1], the 5-septate conidia measure 24 to 40 by 5μ, while in our Gibberella from wheat grains they average 45 to 60 by 5 to 5.5μ and have an absolute fluctuation from 38 to 72 by 4.5 to 6μ. This fact shows that if Saccardo's diagnosis is based on the same fungus it includes only comparatively dry conidia. Thus, the results may be comparable if the influence of such factors as moisture is known. In this case comparison was simple because Gibberella is a characteristic fungus and can not be confused with any other. In species of Fusarium without known ascus stages it is more difficult, since it has been proved that most of the species are ubiquitous, or at least are not confined to a special host. In order to identify these species, a large number of strains must be collected from different hosts and compared with the species described from these hosts in the literature, paying careful attention to the conditions under which the species are found and on which the description is based. In many cases this was impossible, and in

[1] Bibliographic citations in parentheses refer to "Literature cited," pp. 284–285.

some the illustration and description gave complete data. The most questionable method, however, was to base identification of a fungus on exsiccatæ alone. Dried specimens often contain stages collected from a moist location, drying out later, causing constrictions and other changes in the general shape and curvature of the spore so that even the collector would not always recognize his own specimens if he did not know the cause of these changes. The cross walls or septa of the spores in overwatered cultures are frequently absorbed, a condition often considered as normal in old genera and many species of Fusarium. It is not known whether species with long sickle-shaped conidia of the unicellular type exist in this genus, but it is evidently not the rule. Unicellular normal spores of the small ellipsoidal stage, however, exist in all species of Fusarium and form a normal stage in some sections, such as Elegans. These unicellular spores aid in the rapid distribution of a disease. In other sections, such as Discolor and Roseum, the unicellular type is normal in particular species, but subnormal in most others. This fact shows that exsiccated specimens of Fusarium containing a mixture of all types of conidia do not allow an exact determination when they are collected from nature.

I. FUSARIUM Link

A. SECTION MARTIELLA[1]

[Species in section Martiella are *Fusarium solani* (Mart.) Sacc., *F. martii* App. and Wollenw., *F. coeruleum* (Lib.) Sacc., and *F. radicicola*, n. sp.]

Fusarium radicicola, n. sp.

Diagnosis.—Conidia, normally 3-septate, may occur scattered in sporodochia or pionnotes, averaging 30 to 45 by 3.75 to 5μ; 25 per cent of the total number may be 4-septate; 5 per cent may be 5-septate and average 40 to 50 by 4 to 5.25μ. Chlamydospores, 7 to 10μ, agree with those of other species of the section Martiella.

Habitat.—On partly decayed tubers and roots of plants, such as *Solanum tuberosum* in Europe and America (collected by Wollenweber) and *Ipomœa batatas* in the United States of America (collected by Harter and Field).

Fusarium radicicola (Pl. XVI, fig. K) has the characters of the section Martiella. The conidia are narrower than in *Fusarium solani* (Mart.) Sacc. (sensu strict.), which has 3-septate conidia averaging 30 to 40 by 5 to 6μ in size and are shorter and have fewer septations than in *F. martii* App. and Wollenw., which has 3- to 4-septate conidia averaging 44 to 60 by 4.75 to 5.50μ in size. The plectenchymatic mycelium is olive colored on sterilized potato tuber, with all shades from green to brown. The description has been made from a strain isolated from an Irish potato tuber grown in 1912 on the Potomac Flats, near Washington, D. C.

Fusarium radicicola resembles slightly the conidial stage of *Hypomyces cancri* (Rutg.), n. comb. (Pl. XIII, fig. *J*), but has no pedicellate base

[1] The author established these sections (Wollenweber, 1913*a*) with the diagnoses of the species and references to complete previous descriptions (Appel and Wollenweber, 1910).

(Pl. XVI, fig. *K*). It is often isolated from Irish potato, especially from dry tubers affected with stem-end dry-rot. Sometimes it is associated with other organisms, but frequently seems to invade the tuber from the stolon before a cork layer has been formed to protect the stem end from outside infection. It has never produced the perfect stage. So far there is no sound basis for the supposition that it might be a strain of Hypomyces which has lost the power of producing the perfect stage. The fungus occurs in Idaho, Oregon, and California, and probably in other Western States, and also in all of the New England States except the most northern. Its presence on the sweet potato suggests that it might require a higher optimum temperature than its related species, such as *F. solani* and *F. martii*. Inoculation experiments with strains from different sources are desirable in order to throw more light on the relationship of the above-mentioned fungi and their comparative effect on their hosts.[1]

B. SECTION DISCOLOR

[Species in this section are *Fusarium discolor* App. and Wollenw., *F. discolor*, var. *sulphureum* (Schlecht.) App. and Wollenw., *F. culmorum* (W. G. Sm.) Sacc. (Syn. *F. rubiginosum* App. and Wollenw.), and *F. incarnatum* (Rob.) Sacc.]

Fusarium incarnatum (Rob.) Sacc.

Fusisporium incarnatum Rob.; Desm., 1849, *in* Ann. Sci. Nat. Bot., s. 3, t. 11, p. 274.

Fusarium (*Fusisporium*) *incarnatum* (Desm.) Sacc., 1881, *in* Michelia, v. 2, no. 7, p. 296.

Fusarium incarnatum (Desm.) Sacc., 1886, Syll. Fung., v. 4, p. 712.

Fusarium incarnatum Desm., ex McAlp., 1899, Fung. Dis. Citr. Trees Austral., p. 106, fig. 141.

Fusarium neglectum Jacz. (1912 *in* Bul. Soc. Mycol. France, t. 28, fasc. 4, p. 340–348, fig. 4) is probably a synonym of *F. incarnatum*.

Diagnosis.—As a rule no sporodochia, no pionnotes, and no chlamydospores, but olive-brown plectenchymata of remarkable longevity are produced. The conidia, formed into a salmon-colored powder, are embedded in a floccose lanate mycelium of the same color. The fungus therefore resembles *Fusarium trichothecioides* Wollenw. in general appearance. Subnormal conidia are unicellular or septate, rounded at the ends, seldom pointed (Pl. XIII, fig. *H*, *a*). Normal conidia show characters of the section Discolor (Pl. XVI, *L*), but are less curved and have mostly a conical (Pl. XIII, fig. *H*, *b*), seldom a pedicellate base (Pl. XIII, fig. *H*, *c*). Slender conidia (Pl. XIII, fig. *H*, *b*) occasionally are seen but should not be confused with the section Elegans (compare *F. orthoceras*). Triseptate conidia measuring 20 to 25 by 3.5 to 4.5μ, and 5-septate conidia, 30 to 50 by 3.75 to 5μ, may be predominant; 10-septate conidia occur more rarely. The conidiophores, mostly irregularly branched, show sometimes slightly verticillate ramifications. Chlamydospores are seldom present and are formed intercalated from hyphæ, or occasionally from conidia.

Habitat.—A cosmopolitan species. It is found in the stems, leaves, fruits, roots, and especially the inflorescences. It occurs rarely on monocotyledons, but has been obtained from Zea, Asparagus, and Iris. This species is confined mostly to dicotyledons and has been found on the following genera: Agrostemma, Dianthus, Brassica, Lupinus, Citrus, Ipomoea, Hyoscyamus, Solanum, Rhinanthus, Campanula, Aster, Tagetes, and Tussilago. It occurs in Europe, America, and Australia.

[1] Compare also the notes under *F. orthoceras*, a species connected with jelly end-rot, a serious trouble in California.

Desmazieres gave in 1849 a short and incomplete description of this fungus, calling it *Fusisporium incarnatum* Roberge, following the designation given by Roberge, the collector of the original material, which consisted of affected inflorescences of *Tagetes erecta*. In 1881 the fungus was transferred to Fusarium by Saccardo in Michelia; it also occurs in Sylloge Fungorum (Pls. XIII, fig. *H*, and XVI, fig. *L*). The best description of this cosmopolitan species is given by McAlpine (1899), who well illustrated the conidia from a citrous stem. He found the fungus associated with *Gibberella pulicaris* in October, 1878, at Ardmona, Victoria, Australia.

The present author, although basing this diagnosis on a strain from Ipomoea, has compared pure culture strains from a wide range of hosts. In looking over the flowers in ornamental gardens late in the summer, one can easily see the pink powder formed by this fungus on plants such as Aster, Iris, Dianthus, Campanula, and Tagetes. It occurs on stems and inflorescences and is not confined to ornamental plants, as proved by its presence on the dead stems and seed bolls of Hyoscyamus, a wild plant common in the United States. Determinations of strains from sweet potato showed its occurrence on the roots. In Germany dead stems of Lupinus are also inhabited by *Fusarium incarnatum*. Although the effect of this fungus on the living plant remains to be worked out, its cosmopolitan and ubiquitous nature seems fully established by these comparative morphologic studies.

A relative of *Fusarium incarnatum*, which often has been found associated with Gloeosporium, occurs on the fruit of the banana. This Fusarium, *F. semitectum* B. and Rav., has smaller conidia and in the average fewer septa than *F. incarnatum*. Inoculation experiments are desirable to throw further light on the simultaneous relations of these organisms. This species is different from that described from carnations by Clayton J. Wight (1912), because it develops neither a lemon-yellow nor a wine-red color on rice; it has no true chlamydospores, and the peculiar curvature of the conidia (Pls. XIII, fig. *H*, and XVI, fig. *L*) gives it a special place in the genus.

Fusarium dianthi Prill. and Delacr. (Delacroix, 1901) also is not identical with our species. Its relation to diseases of Aster is also doubtful.

Fusarium incarnatum is of morphologic interest because of the absence of sporodochia and pionnotes. Such species in general are less constant in form and septation than those with sporodochia, but successive transfers to fresh culture media, such as stems of legumes and tubers of potato, will establish sufficient constancy to justify the interpretation of the illustrated conidia (Pls. XIII, fig. *H*, and XVI, fig. *L*) as normal. *F. incarnatum* may be provisionally placed in the Discolor section until related species now under investigation require a separation, which may be accomplished either by establishing a subsection of Discolor for them

or an independent section which could be called "Lanceolata" because of the conidia being lanceolate, especially when seen from the back (Pl. XIII, fig. *II*, 4).

3. **Fusarium culmorum** (W. G. Sm.) Sacc.

Fusisporium culmorum W. G. Sm., 1884, Dis. Field and Card. Crops, p. 208-210, fig. 92.

Fusarium Schribauxi Delacr., 1890, *in* Bul. Soc. Mycol. France, t. 6, fasc. 2, p. 99, pl. 15, fig. 1; Sacc., 1892, Syll. Fung., v. 10, p. 726.

Fusarium culmorum (W. J. Sm.) Sacc., 1895, Syll. Fung., v. 11, p. 651.

Fusarium corallinum Mattirolo (non Sacc.), 1897, *in* Mem. R. Accad. Sci. Ist. Bologna, s. 5, t. 6, p. 677, fig. 16-17.

Fusarium rubiginosum App. and Wollenw., 1910, *in* Arb. Biol. Anst. f. Land- u. Forstw., Bd. 8, Heft 1, p. 108, pl. 1.

Diagnosis.—Conidia scattered in sporodochia or in pionnotes in masses ochreous to salmon colored, 5-septate, averaging 30 to 45 by 5.5 to 7μ, seldom 3 to 4-septate, rarely with a larger or smaller number of septa. The slight constriction at the apical end and the pedicellate base of normal conidia make this fungus a type species of the section Discolor. Conidiophores in sporodochia increase to repeatedly verticillate ramifications with sterigmata and side branches as many as four in whorls. The mycelium thallus has a yellow acid modification (viz, on rice) turning violet with alkaline and a carmine-red basic one (viz, on wheat and potato tuber) turning yellow with acid. Chlamydospores intercalated, single, in chains or in clusters, averaging 7 to 14μ in diameter.

Habitat.—This species is found in Europe and North America on all parts of partly decayed plants. It is a wound parasite on cereals and causes scab and seedling blight (foot disease). It has been found on the following hosts: Zea, Avena, Triticum, Secale, Hordeum, Lupinus, Gossypium, Ipomoea, Beta, Solanum, Cucumis, Cucurbita, and others.

This diagnosis is based on the original strain from an Irish potato tuber at Dahlem, near Berlin, described as *Fusarium rubiginosum* by Appel and Wollenweber (1910) and is changed only in the minimum average width of conidia and in the distribution of the fungus.

When the writer studied species of Fusarium on the potato in Germany, he isolated *Fusarium culmorum* (Pl. XVI, fig. *J*) from tubers affected with dry-rot and described it as *Fusarium rubiginosum* App. and Wollenw. In pure culture it attracted special attention by its carmine color on steamed potato tuber. This color always indicated its basic modification, while the red turned chrome yellow with acids. An acid-yellow modification of the fungus, which turned violet by addition of alkali, appeared naturally on steamed rice. This fungus was noted by Schaffnit in his important studies of the "Schneeschimmel" of cereals (Schaffnit, 1913); he stated a similar range of color shades and illustrated this organism very well.

The conidia of this fungus are characterized by a thick membrane and very pronounced cross walls (septa). In maturity they are of ochreous color, lighter in small quantities and darker when seen in masses, but in young culture, especially in moist pionnotes on potato tuber, they may have salmon shades. The presence of chlamydospores facilitates the determination when under certain conditions. The conidia

(Pl. XVI, fig. *J*) resemble those of *Gibberella Saubinetii* (Pl. XVI, fig. *O*). The latter ascomycete has no chlamydospores, as pointed out by the writer (Wollenweber, 1913c, p. 31). This fungus did little damage on potato tuber in several inoculation experiments. Its more destructive nature as a cause of damping-off of oats and wheat (Wollenweber, 1913c, p. 31, 45) has been established by E. C. Johnson (1914). L. H. Pammel (1905) and others have repeatedly called attention to *Fusarium culmorum* as a cause of blight of wheat, barley, and oats in America. Schaffnit (1913, p. 612) described similar effects of the fungus on artificially weakened seedlings of rye.

We can not overlook the fact that students of the "Schneeschimmel" and foot disease of cereals are still endeavoring to appoint perfect stages for species of Fusarium. Voges (1913) illustrates two species of Fusarium on cereals which we easily recognize as *F. metachroum* App. and Wollenw. and *F. culmorum* and thinks he has proved the latter to be the conidial stage of *Ophiobolus herpotrichus* Fr. (Voges, 1912). The present writer, however, has studied Ophiobolus in pure culture and grew normal perithecia on steamed stems of Lupinus and on straw. No sickle-shaped conidia developed in pure culture from any of the stages of the fungus, and no Ophiobolus appeared in pure cultures of any of the species of Fusarium associated in nature with this ascomycete. Voges's studies do not seem to be based on sufficient successful pure-culture work to withstand an unfavorable criticism of his conclusions.

The writer was especially interested in the geographic distribution of *Fusarium rubiginosum*, a study begun in Dahlem. He mentioned (1911, p. 21) its occurrence on Zea, Triticum, and Avena. In the United States this fungus was sometimes isolated from Ipomoea, but its predominant presence on many cereals seems to indicate its better adaptation to the Gramineae, especially to those grown in the warmer part of the Temperate Zone. These facts made desirable a second revision of the described species of Fusarium on cereals, as a result of which it was found that the name *F. rubiginosum* should give way to *F. culmorum*. The illustration (Smith, 1884, fig. 92) leaves no doubt of its identity with this species. It has also been found in France, where Delacroix called it *F. Schribauxii*. Mattirolo (1897), in his interesting studies on Cerebella, seems to have worked with the same fungus. He calls it *F. corallinum* Sacc., but illustrates swollen conidia of *F. culmorum*.

It may be noted that the name "Cerebella" refers to an old genus established by Cesati in 1851. Among the various fungi connected with this stage, *Fusarium* spp. play a part, and Mattirolo's studies suggest that it is the pionnotes stage developed by some species which has caused the confusion with Cerebella.

C. SECTION GIBBOSUM

[Species in section Gibbosum are *Fusarium gibbosum* App. and Wollenw., *F. falcatum* App. and Wollenw., *F. sclerotium* Wollenw., *F. caudatum*, n. sp., *F. caudatum*, var. *volutum*, n. var.]

4. **Fusarium caudatum**, n. sp.

Diagnosis.—Conidia with a tail or whiplike prolongated apical cell and a pedicellate base with well-marked heel, ochreous to salmon colored in mass, formed in sporodochia and in pionnotes; 5-septate conidia averaging 40 to 80 by 3 to 4.5μ, lower and higher septations more rarely occur. Brown chlamydospores, 7 to 14μ in diameter, as a rule intercalated in chains or clusters, but frequently single if formed from the content of the cells of conidia under poor conditions, such as in water.

Habitat.—On partly decayed stored sweet potatoes (*Ipomoea batatas*) from Clemson College, S. C. (Collected by Harter and Field.)

This species differs mainly from *Fusarium gibbosum* in having more slender conidia, with a prolonged apical cell and a less pronounced hyperbolic curve of the dorsal side.

The hyperbolic curvature of the conidia, when seen in side view, is not as pronounced with *Fusarium caudatum* (Pl. XVI, fig. *M*) as it is with *F. gibbosum*. This is due to the more slender form of *F. caudatum*. All the other characters point at once to the section Gibbosum. The long and whiplike projection of the apical cell, the pedicellate base, with the long foot adorned by a heel (Pl. XVI, fig. *M*), the clusters and chains of chlamydospores, the formation of intra- and extra-cellular conidio-chlamydospores (see Pl. XVI, fig. *A*, 4) in very moist culture conditions—all these are invariably connected with species of this section, such as *F. gibbosum*, *F. sclerotium*, and *F. falcatum*. The morphology of the first species is referred to; this is completely described by Appel and Wollenweber (1910). *F. caudatum* differs in having a more slender form, being longer and narrower when compared with *F. gibbosum* (30 to 60 by 4 to 5.25μ). The tail or whiplike prolonged apical cell is a special character of this fungus, which also forms an abundant pionnotes when single 5-septate conidia are transferred to steamed potato tuber.

A similar but higher septate species of the same section occurs on potato stems, but has more septa and conidia up to 100μ in length. This and a strain from pine seedlings require more study before a definite determination can be made.

However, a variety of *Fusarium caudatum* with more curved and smaller conidia is added here and named *F. caudatum*, var. *volutum* (Pl. XVI, fig. *P*). Both forms are isolated only from sweet potatoes. Their frequency and distribution remain uncertain.

Comparative studies on chlamydospores show that the section Gibbosum deserves a higher rank in the genus than the section Discolor, although both show a remarkable development in the production of this hibernating form. Clusters and chains of chlamydospores are produced in species of both sections. They may even predominate if water has been liberally furnished. The simplest form of a chlamydospore is a globose or pyriform cell with a thick membrane consisting of at least two

layers in maturity. Two-celled chlamydospores, often produced among unicellular ones, are the first indication of a higher development. Irregular, formless clusters consisting of many chlamydospores are still higher in rank, and the highest type seems to be that cluster distinguished by a true spherical form. Such spheres have been produced only in *Fusarium sclerotium* Wollenw. of the section Gibbosum (Wollenweber, 1913c, p. 32), and all intermediate stages from the unicellular spore to this blue solid body could be observed in pure cultures on steamed wheat heads and potato tubers. These bodies are doubtless true sclerotia. Their peripheric layer has large cells of dark-blue color. The central part is almost colorless and of small-celled parenchymatic structure when sclerotia 50 to 80μ in size are studied in cross section.

The fact that these sclerotia can be traced back to unicellular chlamydospores proves the close relation of these two resting stages, and the unsuccessful attempt to produce a perfect form in this species leads to the opinion that sclerotia replace the perfect stage in this species of Fusarium. There is no basis for the conclusion that these massive bodies might represent immature perithecia, because Gibberella, Nectria, and Calonectria never have such a uniform structure in the center of the perithecia in similar phases of their development. Consequently it may be concluded that the section Gibbosum has species with chlamydospores, such as *F. gibbosum*, *F. falcatum*, and *F. caudatum*, and other species with sclerotia besides chlamydospores, such as *F. sclerotium*, but none with a known perfect stage. While the section Discolor has species with chlamydospores, it has none with sclerotia and none with a known perfect stage.

5. **Fusarium caudatum, var. volutum,** n. var. (Pl. XVI, fig. *D*).

Diagnosis.—Conidia 3- to 5-septate, averaging 25 to 50 by 2.5 to 4μ in size. Conidia more curved, smaller, and with fewer septa than *Fusarium caudatum*, but agreeing in all other characters.

Habitat.—On partly decayed stored sweet potatoes (*Ipomoea batatas*), La Fayette, Ind. (Collected by Harter and Field).

D. SECTION ELEGANS

[Species in this section are *F. oxysporum* Schlecht., *F. hyperoxysporum*, n. sp.; *F. tracheiphilum* Smith; *F. vasinfectum* Atk.; *F. lycopersici* Sacc.; *F. niveum* Smith; *F. redolens* Wollenw.; *F. orthoceras* App. and Wollenw.; *F. orthoceras*, var. *triseptatum*, n. var.; *F. batatatis*, n. sp.; and *F. conglutinans* Wollenw.]

6. **Fusarium orthoceras** App. and Wollenw.

Fusarium orthoceras App. and Wollenw., 1910, *in* Arb. Biol. Anst. f. Land- u. Forstw., Bd. 8, Heft 1, p. 1–207, 10 fig., 3 pl.

Fusarium orthoceras App. und Wollenw., Wollenweber, 1913, *in* Phytopathology, v. 3, no. 1, p. 30.

Diagnosis.—Conidia as a rule unicellular, averaging 5 to 12 by 2.5 to 3.5μ, embedded in a cottony mycelium layer, often jellied with age. No sporodochia, no pionnotes, and no sclerotia. A few, not exceeding 15 per cent, of the conidia, averaging 25 to 46 by 3 to 4μ, may be 3-septate. Septal zone nearly cylindrical, slightly curved at the apical end, which is unequilateral-conical; the base is nearly straight-conical and may or may not end in a very reduced foot; 4- and 5-septate conidia rare, averaging up to 50 by 4.0μ; conidiophore with irregularly arranged sterigmata, seldom tri-

furcate. The fungus is ochreous to salmon colored in light, in darkness it fades to brownish white. Thalloplectenchymata wine red in the acid modification (on rice) and blue spotted in the basic modification (on potato tubers); but sclerotial plectenchymata entirely wanting. Chlamydospores intercalated, globose to ovoid, 1-celled forms averaging 7 to 10μ, 2-celled forms more rare but with a somewhat larger major axis.

Habitat.—A cosmopolitan species. Inhabits the root system of such plants as Allium, Brassica, Ipomoea, Solanum, Capsicum, Apium, Citrullus. This species is especially abundant in North America. Probable cause of jelly end-rot of potato tubers and root troubles.

In Europe this fungus is confined to the cooler part of the Temperate Zone. In Germany and Norway it is common on the tuber, the stolon, and other parts of the root system of *Solanum tuberosum*. In America at least 20 strains of this fungus from potato have been added to the writer's collections, which were mostly transferred to him in pure culture for determination. The following States may be recorded as sources of this material: Tennessee, New York, Vermont, Maine, Ohio, Illinois, Iowa, Wisconsin, Minnesota, Washington, Oregon, California, and the District of Columbia. Furthermore, *Fusarium orthoceras* was sent with potatoes from Cape Colony, Africa, and from Chiloe, South America, also from Great Britain. These additional isolations proved its cosmopolitan nature. In the Bureau of Plant Industry, Washington, D. C., the fungus was frequently isolated and determined from diseased plants, such as onion, cabbage, sweet potato, celery, and occasionally from watermelon (Citrullus) and sweet pepper (Capsicum). The determination of this species is somewhat handicapped by the predomination of unicellular conidia, but repeated transfers and variation of media are sufficient means to provide sickle-shaped septate spores of typical form. The conidia and the chlamydospores, the mycelium with its jellied growth in old cultures, and its deep wine-red to purple-acid modification (turning blue with alkali) on rice allowed the final determinations

Only a few, not exceeding 15 per cent, of the conidia are 3-septate, as indicated in the diagnosis of the type strain studied in Berlin. This low percentage of the characteristic sickle-shaped conidia was quite uniformly found in many strains from the same or from different host plants. However, one strain out of several isolated from *Ipomoea batatas* had as many as 100 per cent of 3-septate conidia (Pl. XVI, fig. *N*) under the same conditions, where the other strains had but a few per cent of them.

7. **Fusarium orthoceras,** var. **triseptatum,** n. var.

Diagnosis.—Differs from *Fusarium orthoceras* in having a higher septation of conidia, by the presence of sporodochia, and a reduced pionnotes. Under normal conditions as many as 100 per cent of the conidia are 3-septate. Ten per cent of 4- and 5-septate conidia are found. Unicellular conidia and chlamydospores occur and prevail under certain conditions.

Habitat.—On partly decayed roots of *Ipomoea batatas*, Newark, Del. (collected by Taubenhaus, 1912).

In order to find whether or not one type strain of *Fusarium orthoceras*, var. *triseptatum* (Pl. XVI, fig. *N*), could be split up into strains with different percentages of unicellular and septate conidia, the writer separated 20 conidia from a subculture of a single spore and transferred each to a test tube on potato tuber. Some of these conidia were sickle-shaped and septate, but most of them unicellular. No differences could be observed as to a remarkable increase of 3-septate conidia, nor was there a sign of sporodochia. While the exceptional strain exposed to the same treatment did not degenerate to a strain with predominantly unicellular conidia, it produced sporodochia on stems in contrast to the type strain. It seems better, therefore, to separate this strain provisionally from the others as a variety, unless this contradiction is cleared up by more advanced culture methods. The name "*F. orthoceras*, var. *triseptatum*, n. var.," is therefore proposed.

Fusarium orthoceras and its variety are provisionally included in the section Elegans, although their conidia have no true bottle-shaped apical cell and scarcely a pedicellate base. Inoculation experiments are needed to ascertain whether or not this fungus is the cause of one type of jelly end-rot of potato tubers. In Watsonville, Cal., in October, 1913, the writer found up to 80 per cent of Burbank potatoes in a large acreage affected by this peculiar soft rot, which is quite different from that produced by *F. coeruleum* and other species. Every year specimens with this disease are sent from California, especially from the moorland (called "tule district") of the San Joaquin Valley. In tubers with the jelly end-rot *F. orthoceras* is often, but not always, associated with such fungi as *F. radicicola*, *Mycosphaerella solani*, *Sporotrichhum flavissimum* Lk., Rhizoctonia, and also with bacteria. It may be repeated (Wollenweber, 1913c, p. 30) that *F. orthoceras* has been sent to the writer from various sources in pure culture under the name "*F. oxysporum* Schlecht." and that *F. gibbosum* has been sent under the name of the latter species. The complete descriptions and illustrations of these fungi will help to determine and differentiate them, and future inoculation experiments, based on these well-known organisms, will succeed in reducing contradictory reports to a minimum.

The section Elegans plays the most important part in the species of Fusarium on sweet potato because it comprises 4 species determined out of 16 strains from various sources, isolated and reisolated from Ipomoea. When all of them were at the height of growth, the morphologic characters were noted and illustrated. Then inoculation experiments, carried out by L. L. Harter and Ethel C. Field, showed that strains reisolated from successfully inoculated plants remained as constant as in the old cultures. This has been proved to be so, and the considerable time devoted to get these results seems to have been well spent. Two years ago, when this study began, it was the opinion of the

writer that all strains belonging to the section Elegans agreed closely enough to justify their determination as varieties of *Fusarium vasinfectum* Atkinson. At the height of growth, however, the conidia differed in the finer form, the size, septation, and in color shades. The production of sporodochia and pionnotes, the color of mycelium, and such functions as the pathogenicity offered other determinative factors. Secondary characters, such as the production of odors on steamed rice, wheat, and corn, also aided the differentiaton. Two species, their subcultures and reisolations, are proved to be xylem parasites by Harter and Field. These species produced wilt disease, while others refused to do so. The latter agreed in morphology either with *F. oxysporum* or with *F. orthoceras*, the former differed and have been described as *F. batatatis* and *F. hyperoxysporum*. The differences illustrated in Plate XVI, figs. *D* and *F*, and described in the diagnosis are striking to the writer, but he knows that there is one weak point which allows criticism of his opinion. He was unsuccessful for two years in the attempt to transform one of these fungi into the other. However, it is of fundamental value and of vital importance in the classification to find out whether these conclusions are right or wrong, and strains of the various fungi of this section will be available to anyone who may care to throw further light on the complicated problem of drawing the border line between species, subspecies, varieties, and subvarieties, or proving that border lines do not exist to the extent claimed in this paper.

It seems at first probable that there is only one fungus causing the same disease on one host, but okra (*Hibiscus esculentus*) and eggplant (*Solanum melongena*) are attacked by Verticillium in one district and by Fusarium in another district, although the wilt symptoms are so similar that isolation and study of the parasite are the only means of deciding which fungous genus is connected with the trouble in each case. Furthermore, at least three serious wound parasitic species of Fusarium cause potato tuber-rot. Here, also, the isolation of the fungus, not the general appearance of the tuber, decides the question which parasite does the damage. In some cases the climate and methods of cultivation are essential. They offer ideal conditions for one fungus, but not for the other. But this is not always so, and the zone of distribution of one fungus overlaps that of the others. These facts may become important for the control of disease, and the good results performed by an exchange of seed may not be due simply to climatic factors, but to the weakening of parasites by a change of their optimum environmental conditions. Of course, a change of climate may be fatal to the fungus and its host, but there is no reason why it should not be supposed that a zone exists where the host thrives well and the parasite degenerates. Often, however, if one parasite has been successfully controlled, there will soon be another. Control methods may be greatly aided by a careful study of the parasites. In finding what is

normal, abnormalities and conditions which lead to them may be determined. Abnormalities of one fungus, unfortunately, may resemble the norm of another. Without studying the criteria of the norm, two fungi may be mistaken for one. Literature shows that this error leads to more trouble than the mistake of drawing too sharp a border line between closely related species.

Fusarium batatatis differs from *F. hyperoxysporum*. The conidia of the former are 11 to 13 times longer than broad (Pl. XVI, fig. *D*), while those of the latter are 8 to 9 times longer than broad (Pl. XVI, fig. *F*). The apical cell is slender in the former, while bottle-shaped in the latter. The base of the latter is more pronouncedly pedicellate than in *F. batatatis*. The microconidial stage prevails in *F. batatatis*, giving the pure culture on steamed potato tuber a powdery appearance. However, a few of the larger septate sickle-shaped conidia will be found scattered among microconidia. These macroconidia (Pl. XVI, fig. *D*), repeatedly selected, and cultured separately, will result in the reduction of the microconidia and the aerial mycelium to a minimum, so that a perfect pionnotes (Pl. XII, fig. *B*) can be produced on the very same substratum. This pionnotes produces abundant chlamydospores (Pl. XVI, fig. *B*) and redevelops microconidia in old age (Pl. XVI, fig. *C*), which look like a parasitic growth on the spore slime of the former. There is no difficulty in favoring the production of a particular stage, and one stage can easily be transformed into the other, but the constant tendency to form microconidia is characteristic of this fungus. In order to study the stroma, transfers of mycelium or microconidia were made to potato cylinders. The fungus rapidly formed a thallus-like layer (stroma) covering the surface of the substratum. When the potato was sufficiently decomposed and its water consumed by the fungus, the stroma became shriveled. Blue blisters of sclerotial structure smaller than a pinhead appeared at this time by hundreds within the stromatic layer. These sclerotial bodies (Pl. XII, fig. *A*) correspond to the stroma of sporodochia as proved in parallel cultures on steamed stems of sweet potato, potato, or sweet clover. They develop within the epidermis of the stems and often push through in order to develop a convex layer of the sickle-shaped macroconidia. The stromatic thallus on potato tuber is unnecessary for the fungus on stems, and is replaced by endodermatic hyphæ which develop the sclerotial base of the sporodochia described. The blue bodies having a plectenchymatic structure may be called sclerotial plectenchymata. If they are spherical, as in *F. sclerotium*, the writer has called them sclerotia, and there is reason enough for not drawing too sharp a distinction between these different types.

The blue color turns red with acids, and a wine color on steamed rice (Pl. XII, fig. *C*) which turns blue with alkali shows the reverse effect of the reaction the fungi produce when grown on different media.

Fusarium hyperoxysporum has larger but fewer sclerotial bodies on potato tuber. Consequently the sporodochia are larger in this species than in *F. batatatis*. A lilac odor is present in cultures on rice, also on potato tuber, but weaker, while *F. batatatis* has a weak alcoholic odor. A perfect pionnotes can be easily produced with *F. hyperoxysporum* on potato tuber, but is always accompanied by or embedded in aerial mycelium. This fungus resembles more closely *F. oxysporum*, which, however, does not produce wilt disease on Ipomoea. While *F. batatatis* is related to *F. orthoceras*, it differs in characters of the sporodochia, which may be compared in the diagnosis. A number of finer details can be found.

8. Fusarium batatatis, n. sp. (Pls. XII and XVI, figs. *A-E*).

Diagnosis.—Conidia both scattered and in sporodochia or pionnotes, when scattered mostly unicellular. Conidia mostly 3-septate, rarely 4- and 5-septate, when in sporodochia or pionnotes ochreous to salmon colored. Brown chlamydospores and blue sclerotial plectenchymata present. Conidia measure as follows: Unicellular forms, 5 to 12 by 2 to 3.5μ; 3-septate, 25 to 45 by 2.75 to 4μ; 4- to 5-septate, 37 to 50 by 3 to 4μ. Brown chlamydospores, 7 to 10μ thick and similar to those of *F. orthoceras*. The septate conidia are of the same size as corresponding conidia of *F. orthoceras* and differ in shape from *F. oxysporum* in being a little more slender. The blue sterile sclerotial bodies at the base of the sporodochia have a blister-like appearance between the felty powdery dry stroma of scattered conidia and push either through the epidermis or stems or the thallus covering the substratum. According to recent investigations of L. L. Harter and Ethel C. Field, this species causes the wilt (stem-rot) of *Ipomoea batatas* by invasion of the fibrovascular bundles of the stems and roots. (Collected by Harter and Field.)

9. Fusarium oxysporum Schlecht.

Fusarium oxysporum Schlecht., 1824, Fl. Berol., pars 2, p. 139.
Fusarium oxysporum Schlecht., Erw. Sm. and D. B. Swing., 1904, *in* U. S. Dept. Agr. Bur. Plant Indus. Bul. 55, 64 p., 8 pl.
Fusarium oxysporum Schlecht., Manns, 1911, *in* Ohio Agr. Exp. Sta. Bul. 229, p. 299-336, illus.
Fusarium oxysporum Schlecht., Wollenw., 1913, *in* Phytopathology, v. 3, no. 1, p. 28, 40-45, illus.

Diagnosis.—Conidia both scattered and in sporodochia or reduced pionnotes, in mass ochreous to salmon colored. Unicellular conidia, 5 to 12 by 2 to 3.5μ; 3-septate, rarely 4- and 5-septate, conidia from sporodochia, 25 to 42 by 3.25 to 4.75μ. Sclerotial plectenchymata blue with rough surface or even sphærostilbe-like projections. Brown chlamydospores, 7 to 10μ in diameter. This species has a slight lilac odor on steamed rice and milk.

Habitat.—A vascular parasite, cause of wilt disease, but not tuber-rot, of *Solanum tuberosum* in the United States of America, districts of South America and Australia. Also found on various hosts, such as Lycopersicum, Vigna, Pisum, and Ipomoea.

10. Fusarium hyperoxysporum, n. sp. (Pl. XVI, *F*).

Diagnosis.—In morphology of various spore forms and the slight lilac odor, this species agrees with *F. oxysporum*, but differs in having a perfect pionnotes. This species, however, differs biologically from *F. oxysporum*, since it has been proved by L. L. Harter and Ethel C. Field to cause a wilt disease (stem-rot) of *Ipomoea batatas*, but not of *Solanum tuberosum*. On the other hand, *F. oxysporum* causes the well-known wilt disease of *Solanum tuberosum*, but is not infectious on *Ipomoea batatas*.

E. SECTION ROSEUM

[Species of this section are *F. subulatum* App. and Wollenw., *F. metachroum* App. and Wollenw.; *F. putrefaciens* Ostw.; and *F. acuminatum* Ell. and Ev.]

11. **Fusarium acuminatum** Ell. and Ev.

Fusarium acuminatum Ell. and Ev., 1896, in Proc. Acad. Nat. Sci. Phila., 1895, p. 442.
Fusarium acuminatum Ell. and Ev., Sacc., 1899, Syll. Fung., v. 14, p. 1125-1126.

Diagnosis.—Conidia, scattered, in sporodochia or in pionnotes, orange in mass. Conidia average as follows: 5-septate, 40 to 70 by 3 to 4.5μ; 4-septate (less common), 30 to 60 by 3 to 4.5μ; 3-septate, 20 to 45 by 2.75 to 4.25μ. Conidia of 0-, 1-, 2-, 6- and 7-septations are occasionally found. Subnormal small conidia may be mistaken for conidia of the section Discolor, but normal sporodochia develop on repeatedly whorl-like branched conidiophores, giving the characteristic conidia of the section Roseum. The conidia show in side view hyperbolic or parabolic curves, in contrast to *Fusarium metachroum* App. and Wollenw., the conidia of which are as a rule more nearly straight. Blue globose sclerotia, 50 to 70μ thick, occur and form a striking contrast to the carmine plectenchymatic thallus on starchy media, such as steamed potato tubers. Both blue and carmine are basic modifications of the fungus, while yellow (on rice) is the acid one, turning blue to purple violet with the addition of an alkali.

Habitat.—Occurs on partly decayed plants, especially on stems, roots, and tubers, also on fruits. Found on Solanum, Ipomoea, Fagus (beech nuts), and *Impatiens balsamina* in the United States of America.

Conidia of *Fusarium acuminatum* (Pl. XVI, fig. *G*) have the parabolic dorsal and ventral curvature which is characteristic of the section Gibbosum, but less pronounced in the section Roseum. Gibbosum, however, requires the presence of chlamydospores and the absence of carmine mycelium, while this fungus has no chlamydospores but carmine mycelium. Therefore, it has to be classed under the section Roseum. The mycelium becomes yellow on steamed rice. This acid yellow modification turns violet with alkali. This fungus is more distributed on Solanum than on Ipomoea and has also been found on Impatiens and on beech nuts (Fagus) in the United States. Its conidia (Pl. XVI, fig. *G*) are more curved and more swollen towards the middle of the septal zone than *F. metachroum*, but a remarkable relationship to the latter can not be overlooked.

The strains from Solanum and from Ipomoea agreed in all respects. The diagnosis is derived from a strain isolated from a potato tuber, but many isolations of the same fungus are made from potato stems. The strains from beech nuts and Impatiens were a little more slender and had a whiplike prolonged top cell often resembling that of *Fusarium caudatum*.

Ellis and Everhart (1896) described *Fusarium acuminatum* as follows:

Sporodochia gregarious, minute, white at first, then flesh-colored. Conidia falcate, attenuate-acuminate at each end, 3–5, exceptionally 6 septate, not constricted, arising from slightly elongated cells of the proligerous layer, in which respect it differs from the usual type of Fusarium. . . .

Saccardo's translation (1899) of this diagnosis in Sylloge Fungorum is:

Sporodochiis gregariis, minutis, ex albo carneis; conidiis falcatis, utrinque attenuato-acuminatis, 3–5-, rarius 6 septatis, ad septa non constrictis, e cellulis subelongatis oriundis. *Hab.* in caulibus vivis Solani tuberosi, New York, in America boreali.

This description is incomplete, like many others, but the writer found this fungus so widely distributed on potato stems in the New England States that he feels justified in identifying it as *Fusarium acuminatum*. Blue sclerotial plectenchymata appear in pure cultures on stems of Melilotus, Zea, and a blue color occasionally develops in spots on plectenchymatic bodies on potato tuber and wheat grains.

II. HYPOMYCES (Fr.) Tul.

12. **Hypomyces ipomoeae** (Hals.) Wollenw. (Pls. XIII, figs. *A–G;* XV, fig. *A*, *1–6;* and XVI, fig. *H*).

Nectria ipomoeae, Hals., 1892, *in* N. J. Agr. Exp. Sta., 12th Ann. Rpt., 1891, p. 281–283, fig. 20–22.
Creonectria ipomoeae, Seaver, 1910, *in* N. Amer. Fl., v. 3, pt. 1, p. 22.
Nectria coffeicola, Zimm., 1901, *in* Centbl. Bakt. [etc.], Abt. 2, Bd. 7, No. 3, p. 103–106, fig. 6.
Hypomyces ipomoeae (Hals.) Wollenw., 1913, *in* Phytopathology, v. 3, no. 1, p. 34.
Nectria saccharina, Berk. and Curt., 1869, *in* Jour. Linn. Soc. [London], Bot., v. 10, p. 378, no. 766, is probably a synonym of *H. ipomoeae*.
Nectria Goroschankiniana, Wahrl., 1886, *in* Bot. Ztg., Jahrg. 44, No. 29, p. 503, pl. 3, fig. 17, 22, 25, is probably a synonym of *H. ipomoeae*.

Diagnosis.—Perithecial stage: Perithecia scattered or gregarious, free on the surface of the host as well as embedded in mycelium or on a distinct plectenchymatic stroma, ovoid, subconical, subflask-shaped, averaging 225 to 375 by 175 to 300μ. Peridium strongly verrucose, owing to protuberance-like projections of cell groups, red to reddish brown, except the almost colorless conical beak. A few paraphyses line the inner wall of the throat from the ascus ball to the ostiolum. Asci up to over a hundred in each perithecium, intermixed with a few more celluled paraphyses. Ascospores, 8 in one row or irregularly in two rows, 2-celled ovoid to ellipsoidal with wrinkled exospore, in mass brownish white; one septum, average size, 10 to 13 by 4.5 to 6μ, undermoist overripe condition slightly constricted at the septum. Conidial stage: Conidia scattered in sporodochia or pionnotes, of nearly cylindrical shape at the septal zone, slightly pointed and curved at the ends, base pedicellate without a distinct heel. Conidia, 3 to 5 septate; 3-septate, 30 to 45 by 3.75 to 5μ; 5-septate, 45 to 70 by 4.25 to 5.5μ. Of the total number, 30 per cent may be 6-septate, 10 per cent may be 7-septate, with an average size up to 70 by 6μ. In young, moist, and hunger stages unicellular conidia occur, averaging 6 to 12 by 3 to 4.75μ. Color of conidia masses brownish white, occasionally impregnated with blue, a mycelium color, especially formed in the plectenchymata. Conidiophores verticillately branched. Chlamydospores globose or ellipsoidal, terminal and intercalated, mostly unicellular and scattered, average diameter, 7 to 10μ.

This diagnosis is derived from subcultures of a strain isolated by Dr. Donald Reddick, of Cornell University Agricultural Experiment Station, from a badly rotted sweet potato sent him on April 30, 1907, by J. M. Van Hook, of the Ohio State Agricultural Experiment Station, Wooster, Ohio.

Habitat.—Saprophyte on dead parts of plants. Probably a cosmopolitan and ubiquitous species. Found in North America on *Solanum melongena*, New Jersey; *Ipomoea batatas*, Clemson College, S. C.; and Vineland, N. J. (L. L. Harter and Ethel C. Field, 1912); Newark, Del. (J. J. Taubenhaus, 1912). Also in Asia on *Coffea arabica*, *Melia azedarach*, *Theobroma cacao* (fruit), Java (Zimmermann, sub *Nectria coffeicola*, 1901); *Glycine hispida* Max., *Phaseolus mungo*, var. *subtrilobata* Province Higo, Japan (Yoshino, 1905). In Africa on Cinchona (Zimmermann, sub *Nectria coffeicola*, 1904). In Europe on *Orchydeae* (roots; Wahrlich, sub *Nectria Goroschankiniana*, 1886).

12a. **Hypomyces caneri** (Rutgers), n. comb.[1] (Pls. XIII, *J*, and XV, *B–C*).

Nectria caneri Rutg., 1913, *in* Ann. Jard. Bot. Buitenzorg, v. 27 (s. 2, v. 12), pt. 1, p. 62.

Diagnosis.—In general appearance this species resembles *Hypomyces ipomoeae*, but differs in having a lower average septation of the conidia, larger perithecia, and larger ascospores. Contrary to *H. ipomoeae*, the conidial stage, especially sporodochia and pionnotes, is more prevalent than the ascigerous stage. Perithecia average 350–450 by 275 to 375μ; ascospores average 10 to 15 by 5 to 6.75μ in size; conidia largely 3-septate average 30 to 45 by 3.75 to 5μ (3 to 5 septate conidia average 30 to 55 by 3.75 to 5.5μ in size).

Habitat.—On cankered bark of *Theobroma cacao* in Java (Rutgers), on dead tap-roots of *Cannabis sativa*, Potomac Flats, Washington, D. C., North America (Wollenw.). This diagnosis is based on pure cultures of the strain isolated from Cannabis.

Hypomyces ipomoeae, well known as *Nectria ipomoeae* Halsted (1892), has both true chlamydospores (Pl. XIII, fig. *D*) and conidia of the shape described for similar Hypomyces, such as *H. solani* Reinke and Berthold (1879). Such chlamydospores are lacking in pure cultures of Nectria, as proved by the writer for the sections Willkommiotes and Tuberculariastrum (Wollenweber, 1913b, p. 203–204, 226–229). A transfer of *N. ipomoeae* to the genus Hypomyces is therefore advocated (Wollenweber, 1913c, p. 34). Since further taxonomic discussion on this fungus will be aided by more complete descriptions, additional notes and illustrations (Pls. XIII and XV) have been given here.

This saprophyte, now known to be cosmopolitan and ubiquitous, has crossed the path of various pathologists who always thought it was a new species when they isolated it from other hosts than eggplant and sweet potato. So long as the opinion of its parasitic nature prevailed, an adaptation to particular hosts could be supposed, but its saprophytic nature established by Harter and Field for sweet potatoes and eggplants and by the writer for eggplant leaves no doubt of its indifference regarding the host.

In pure culture the easy and rapid development of perithecia on almost any steamed vegetable recalls the similar omnivorous conduct of other saprophytes, such as Melanospora and Chaetomium, while *Gibberella Saubinetii* and *Nectria discophora* favor some media more than others for the production of the perfect form, and *Nectria galligena* and *Calonectria graminicola* require a careful selection of media for the completion of their life cycle in pure culture.

Hypomyces ipomoeae has been studied in a number of strains from Ipomoea, sent from Ohio, Delaware, and New Jersey, and isolated by L. L. Harter and Ethel C. Field, Bureau of Plant Industry; J. J. Taubenhaus, Delaware Experiment Station; and Dr. Donald Reddick, Cornell Experiment Station. No essential differences could be detected within two years, and it should be noted that Reddick's strain has been carried through cultures since 1907 without showing any degeneration or any

[1] This fungus from hemp, although not yet found on sweet potato, has been discussed in connection with *Hypomyces ipomoeae*, and it was thought advisable to give a short description.

change in its known characters. Sometimes the production of conidia preceding that of the perfect form is more abundant and lasts longer in one culture set than in another of the same strain, but the constancy has been found a function of the constancy of method and medium. The conidia showed a remarkable constancy in shape and size (Pl. XIII, fig. *G*) and had 3 to 5 septa. There was, of course, a fluctuation in the percentage of 3-, 4-, and 5-septate conidia, depending on the medium itself and on the age of the culture. Once the triseptate conidia prevailed, and sometimes the quinqueseptate conidia prevailed, but this fluctuation is constant even if 5-septate conidia are transferred separately. In other words, strains can not be grown with only 5-septate conidia by repeated selection of 5-septate conidia from a fungus with a normal fluctuation of 3- to 5-septate conidia.

In overwatering *Hypomyces ipomoeae*, its septate mature conidia swell and germinate if sufficient food allows further vegetative growth. If the medium is very dilute so that macroconidia can not be formed, microconidia will take their place (Pl. XIII, fig. *F*). While in almost pure water chlamydospores similar to those known in the section Martiella of Fusarium appear on hyphæ (Pl. XIII, fig. *D*, 1-3) or within conidia (conidio-chlamydospore, Pl. XIII, fig. *D*, 4). A transfer to a better medium, such as potato tuber or stems of legumes, will be helpful to produce perithecia. The young perithecium illustrated in Plate XIII, figure *E*, originated from a side branch of a proliferous hypha. The same spiral rolling up can be seen in Neocosmospora. The fungus requires 10 to 14 days for the mature red perithecia (Pl. XIII, fig. *C*) to disseminate their ascospores. If in the meantime cross sections are made from perithecia in various stages of their development, the asci and their remarkable variations from cylindrical to clavate forms can be followed (Pl. XIII, fig. *B*). Paraphyses appear occasionally, but in many preparations they are invisible, owing to their fragility and scarcity. Perithecia may be illustrated with prevalently cylindrical asci, with the clavate form, and with mixtures of both types, depending on the water content of the culture and other conditions. The shape of the asci is so modified by the elasticity of their membrane that this character does not seem to be of taxonomic importance. Water influences the outline of ascospores. Barrel-like, swollen cells (Pl. XIII, fig. *A*, 3) indicate either overmaturity in the presence of too much water or the stage before germination. If the medium is exhausted with water still present, a separation of the two cells can often be seen (Pl. XIII, fig. *A*, 4). This resembles Hypocrea. A slow desiccation of the culture performed after the maturity of the perithecia prevents a swelling of the ascospore and normal mature spores of ellipsoidal shape will prevail (Pl. XIII, fig. *A*, 1). Complete dryness decreases the turgescence, so that mature cells become conical with rounded top. Immature spores, however, may look more pointed then

because their delicate membrane can not withstand the increasing pressure to the same extent.

The influence of water has to be fully studied in order to understand these morphologic changes. The peridium of perithecia may be almost smooth when the lack of water prevents further growth of its cells. If the water and food supply, however, allow further development, protuberance-like projections will show the permanent activity of the peripherical cell complications. Also the periphyses will prolongate and form a compact cone adorning the perithecium with a beak. This beak is almost colorless and contrasts therefore with the red color of the peridium (Pl. XV, fig. *A*). The ostiolum at the top of the beak accumulates the ascospores as soon as the gradual drying out of the medium exerts a pressure on the perithecium. The peridial cells dry out and shrink, pressing the content of the ascus ball through the throat out of the ostiolum. Here they accumulate in a brown mass (Pl. XV, fig. *A*, 2 and 4). If the ostiolum is closed so completely that a higher pressure is required, the ejaculation is more explosive and the ascospores are shot out to several millimeters distance. This agrees exactly with the description given by Dr. Erwin F. Smith for Neocosmospora. Also, the stroma of our fungus is as variable in every respect as in Neocosmospora. It may be reduced to a minimum or grown as a thallus-like effuse layer.

Hypomyces ipomoeae may be a good example for discussing taxonomic difficulties. The diagnosis of this sweet-potato fungus, based on pure cultures, agreed closely with that of *Nectria coffeicola* Zimmermann (1901), a saprophyte on Coffea and Theobroma, also with *Nectria Goroschankiniana* Wahrlich (1886) from roots of *Vanda tricolor*, to some extent with *Nectria cancri* Rutgers (1913) from Theobroma. All these fungi were well illustrated by the authors, but mostly from field material. The differences shown in the following list between measurements from different authors will be understood from a discussion of their origin.

There are two methods of measuring spores, one of which gives the absolute size, the other the average size; the former comprises a much larger fluctuation of the spore size than the latter. The absolute fluctuation, therefore, is likely to include young and immature spores, which are smaller and less characteristic than normal mature spores. This is especially the case when the relations between size and age and septation are neglected. Immature ascospores may be comparatively small, 3 to 5μ in diameter, but broader, 5 to 6μ, in maturity, and still broader, 6 to 8μ, in germination or from overwatering. The absolute fluctuation, 3 to 8μ, is too large to be of any taxonomic value, but the fluctuation of the average breadth, 4.5 to 6μ, has some value because it reduces in a measurable way the limits of the absolute fluctuation. This reduction can be performed by measuring repeatedly hundreds of spores and taking the average size of each hundred. With cultures in different ages,

other averages with deviations from the first series would be obtained. With the same fungus on other substrata we may get still more deviations. In summarizing all results, we get the fluctuations of the average size. Experience has shown that we do not need hundreds, but merely 10 spores from each different culture condition in order to get the normal fluctuation of the average size.

Hypomyces ipomoeae (Hals.) Wollenw. from roots of *Ipomoea batatas* gave in pure culture the following average fluctuation of various stages:

Culture 30 days old on steamed potato tuber:

Perithecia, 250 by 200μ; ascospores, 11 by 5 to 5.5μ; 3-septate conidia, 33 by 4.25μ (6 per cent); 4-septate, 42 by 4.75μ (1 per cent); 5-septate, 55 by 5.25μ (56 per cent); 6-septate, 61 to 5.5μ (31 per cent); 7-septate, 66 by 5.5μ (5 per cent); 8-septate (1 per cent).

Culture 30 days old on steamed potato tuber:

Perithecia, 365 by 302μ; ascospores, 13 by 5.75μ; 0-septate conidia, 12 by 3.5μ (30 per cent); 3-septate, 33 by 4.25μ (60 per cent); 5-septate, 49 by 4.75μ (10 per cent).

Culture 23 days old on wheat heads:

Perithecia, 296 by 253μ; ascospores, 13 by 5μ; 0-septate conidia, 12 by 3.25μ; 3-septate, 36 by 4.5μ; 5-septate, 60 by 5.25μ (90 per cent); 6-septate, 66 by 5.25μ.

Culture 45 days old on cotton stem:

Perithecia, 290 to 338 by 197 to 223μ; ascospores, 12 by 5μ; 3-septate conidia, 35 by 4.25μ (38 per cent); 4-septate (35 per cent); 5-septate, 59 by 4.5μ (25 per cent); 6-septate, 58 by 5μ (1 per cent).

Culture 14 days old on straw; overwatered:

Perithecia not measured; 5-septate conidia, 10 by 5.5μ (100 per cent).

Culture 14 days old on boiled rice:

Perithecia absent; conidia unicellular, 6 to 10 by 3 to 4.75μ.

Culture 20 days old on sterile water:

Chlamydospores, 7 to 10μ; originated from conidia.

The average size was higher in the presence of water than under dry conditions, but the number of septations could occasionally be decreased by overwatering. This table shows the fluctuation of average size and percentage of equiseptate conidia, indicating that 5-septate conidia prevail, being closely followed by 3-septate ones. Of all conidia 31 per cent may be 6-septate, 10 per cent 7-septate, 1 per cent 8-septate, but this is very seldom, and 3- and 5-septate spores will always be predominant in maturity. Young cultures bear more unicellular than septate conidia. The average size of equiseptate conidia is more constant than that of unequiseptate conidia. The perfect form of the fungus offers less difficulties, although fluctuations in the average size of perithecia may be considerable. Ascospores fluctuate but little, except when immature spores are included in the measurements. These measure 3 to 5.75μ in diameter, while mature ascospores average from 4.5 to 5.75μ.

The following list of ascomycetes shows the relationship to *Hypomyces ipomoeae:*

Nectria Goroshankiniana Wahrlich (1886):

Perithecia, 360 by 320μ,[1] ascospores, 12 to 15 by 4 to 5μ; conidia (subnormal), 20 to 30 by 3.3 to 4.4μ; chlamydospores described, but their connection with the perfect form unproved.

Nectria coffeicola Zimm. (1901):

Perithecia, 300 to 400μ; ascospores, 10.5 to 13.5μ; 3- to 5-septate conidia, 40 to 50 by 5μ, chlamydospores (?)

Hypomyces ipomoeae (Hals.) (1892) Wollenw. (1913c):

Perithecia, 200 to 425 by 150 to 350μ (absolute fluctuation); ascospores, 8 to 16 by 3 to 8μ (absolute fluctuation), 3- to 5-septate conidia, 30 to 70 by 3.75 to 5.5μ (average fluctuation); chlamydospores, 7 to 10μ.

Nectria cancri Rutg. (1913):

Perithecia, 400 to 500 by 300 to 400μ; ascospores, 10 to 13 by 3 to 5μ; 3- to 5-septate conidia, 30 to 60 by 3 to 5μ; chlamydospores (?)

The illustrations of these fungi agree closely in the general appearance, but in the size of perithecia, ascospores, and conidia differences are observed. Some of these may be due to the special condition under which the fungus was collected or grown; others may be constant. The fact that fungi looking alike at the first glance will be proved different in pure culture became evident to the writer when he found on the taproot of *Cannabis sativa* a fungus with perithecia resembling those of *Hypomyces ipomoeae*. When this organism was studied in pure culture for a year, measurements of all spore stages were made. As is seen in the diagnosis, this hemp fungus developed larger perithecia and ascospores than *H. ipomoeae*. Its conidia, however, were never predominantly 5-septate, while in *H. ipomoeae* as many as 100 per cent of them can be found. The perithecia appeared slowly in the hemp fungus 20 to 30 days after the culture was started, while *H. ipomoeae* required only 10 to 15 days. Attempts to reduce these differences in size (Pl. XV, figs. *A*, *B*, and *C*), septation (Pl. XIII, figs. *G* and *J*), and rapidity of growth failed. One fungus could not be transformed into the other, although their relationship seems to be beyond question.

Since *Nectria cancri* has the size of the hemp perithecia and the normal mature ascospores illustrated by Rutgers are broader than his diagnosis (10 to 13 by 3 to 5μ) gives, the hemp fungus may be provisionally determined as *Hypomyces cancri* (Rutg.), n. comb. (= *Nectria cancri* Rutg.). The fact that chlamydospores are not mentioned by Rutgers does not detract from this conclusion. The writer grows chlamydospores by overwatering the culture, but this method may not yet be well known.

The remarkable variation in the shape of the neck is illustrated in Plate XV, figs. *B* and *C*, and reminds us of *Nectria moschata* Glück. Plate XV, fig. *B*, shows two perithecia with a stromatic base, which is lacking in the other illustrations.

[1] Measurements of the size lacking in the diagnosis have been derived approximately from illustrated perithecia.

III. GIBBERELLA Sacc.

Gibberella Saubinetii (Mont.) Sacc.

Gibberella Saubinetii (Mont.) Sacc., 1879, *in* Michelia, v. 1, no. 5, p. 513.
Gibberella cyanogena (Desm.) Sacc., 1883, Syll. Fung., v. 2, p. 555.
Gibberella Saubinetii (Mont.) Sacc., Sorokine, 1890, *in* Trudy Obsheh. Estestv. I. Kazansk. Univ., t. 22, vyp. 3, 32 p., 1 pl.
Gibberella Saubanetii (Mont.) Sacc., Selby, 1898, *in* Ohio Agr. Exp. Sta. Bul. 97, p. 40-42, fig. 4.
Gibberella tritici P. Henn., 1902, *in* Hedwigia, Bd. 41, Heft 6, p. 302.
Fusarium roseum autorum.
Fusarium rostratum App. and Wollenw., 1910, *in* Arb. Biol. Anst. f. Land- u. Forstw., Bd. 8, Heft 1, p. 30.
Fusarium tropicalis Rehm, 1898, *in* Hedwigia, Bd. 37, Heft 4, p. 194, is probably a synonym of *G. Saubinetii*.

Diagnosis.—Perithecial stage: Perithecia scattered or gregarious, ovoid to subconical free on the surface of the host as well as embedded in mycelium, or on a tubercular plectenchymatic stroma, which may either push in spærostilbe-like bodies through the surface of the host or remain endophytic, 150 to 250 by 100 to 250μ. Peridium smooth and small celled at the basal part, but large-celled, verrucose occasionally, with protuberancelike projections of cell groups near the apical end, black to the unaided eye (turning red brown with acid reaction), dark blue with transmitted light except the almost colorless often rather prominent beak; asci up to over a hundred in each perithecium, intermixed with a few celled paraphyses; ascospores, 8 in one row or irregularly in two rows, subdorsiventral, fusiform slightly curved, tapering at the ends, ochreous in masses; largely 3-septate, 20 to 30 by 3.75 to 4.25μ (up to 5μ diameter in germination, indicated by a constriction at the septa).

Conidial stage.—In shape the conidia resemble the section Discolor of Fusarium, and are closely related to *Fusarium culmorum*, but differ in being longer, more slender, and less developed in septation; conidia 3- to 5-septate, 30 to 60 by 4.75 to 5.50μ, ochreous in mass. Plectenchyma often carmine red, turning yellow in the presence of acid. No true chlamydospores. *F. culmorum*, on the other hand, has chlamydospores in intercalated chains and clusters.

Habitat.—This description is made from a strain isolated from a wheat kernel that failed to germinate (Dahlem, near Berlin, 1909). The following distribution is based on comparative pure-culture studies of fungi isolated from various hosts from different regions. It was found widely distributed within the Temperate Zone, causing scab disease of different kinds of cereals, especially wheat, emmer, rye, oats, spelt, and corn in Germany, Russia, Italy, and probably elsewhere. It has been isolated from berries of *Solanum tuberosum* at Friedenau, near Berlin, Germany, by the writer, and from sweet potatoes (*Ipomœa batatas*) in storage by Mr. C. A. Ludwig, Lafayette, Ind.

According to Saccardo (Michelia, v. 1, no. 5, p. 513, 1879) the fungus also occurs on dead stems of Conium, Phytolacca, Cannabis, Cucurbita, Convolvulus, Clematis, Beta, Angelica, Stipa, Gyneria, Asparagus, and Scirpus, and on branches of Gleditschia, Rosa, Robinia, Juglans, Fraxinus, Ulmus, Coronilla, Rubus, and Buxus in France, Italy, Germany, Austria, Great Britain, Spain, Belgium, Algeria, North America, and Australia. A. D. Selby, in his "Brief handbook of the diseases of cultivated plants" (Ohio Agr. Exp. Sta. Bul. 214, p. 454, 1910), adds clover (Trifolium) and alfalfa (Medicago) as new hosts. Some of these statements, however, seem to be merely based on the presence of the conidial stage, to which different names have been given, such as *Fusarium roseum* Link, *F. herbarum* (Corda) Fr., and *F. rostratum* App. and Wollenw.

This characteristic fungus, *Gibberella Saubinetii* (Pls. XIV, figs *D–G*, XVI, fig. *O*), is widely distributed on cereals. Sorokine (1890) and Selby (1898) illustrated it well and many authors described its life cycle. Since

all descriptions have been based on field material and not on pure cultures, a few supplementary notes and illustrations may be desirable in order to show how much the conidia of this fungus differ from some species of Fusarium often associated with them in the field, and how slender the ascospores are compared with those of *Gibberella pulicaris*, a fungus often confused with *G. Saubinetii*. Attention has already been given to these points in this paper, and the conduct of this fungus in pure culture has been freely discussed in "Criteria of the norm."

In Table I a record of some measurements is given. The conidia have a range of septation differing with age and substratum, but 3-to 5-septate conidia prevail under various conditions. The average size varies greatly if the septation is neglected, but equiseptate spores fluctuate in small limits only. If we measure the absolute fluctuation of the size, we get, of course, a wider limit. For instance, the absolute size of 3-septate conidia in a 40-day-old culture on steamed potato stems fluctuates from 21 to 39 by 3 to 5.5μ in one preparation, from 24 to 36 by 3.4 to 5.1μ in another, while the average size based on the average of 10 measurements was 30 by 4.25μ. This fact proves an almost general law, which could be given in the rule "The absolute fluctuation of the spore size is a function of the average fluctuation." If 20 per cent of its value is subtracted from and added to 30μ, the result is 24 and 36μ. The same operation extended to 30 per cent gives 21 and 39μ. The breadth, 4.25, treated in the same way gives 3.4 and 5.1μ in one, 3 and 5.5μ in the other case. When the fluctuation of the average size of 3-septate conidia has been obtained, 30 to 46 by 4.25 to 4.5μ, and desire an approximate idea of the absolute fluctuation, the mean proportional, which is 38 by 4.375μ, is taken, 30 per cent added and subtracted, and about 27 to 49 by 3 to 5.75μ is obtained, which corresponds almost with the fact. For this reason the absolute fluctuation, given by Appel and Wollenweber (1910) is left out as superfluous in the diagnoses of this paper.

TABLE I.—*Fluctuation of the average sizes of the conidial and perfect stages of Gibberella Saubinetii based on the average of 10 measurements*

CONIDIAL STAGE

Age of culture.	Pure culture on sterilized—	Average length, breadth, and percentage of equiseptate conidia.											
		0 to 2-septate.		3-septate.		4-septate.		5-septate.		6-septate.		7-septate.	
Days.		μ	*P. ct.*	μ	*P. ct.*	μ	*P. ct.*	μ	*P. ct.*	μ	*P. ct.*	μ	*P. ct.*
7	Potato stem			36 by 4.5	18		11	50 by 5.25	70		1		
12	do			37 by 4.5	30		19	52 by 5	49		4		1
30	do			33 by 4.5	8	43 by 5	23	45 by 5	69				
40	do		2	30 by 4.25	68		22		8				
3	Potato tuber		12	37 by 4.50	50		12	47 by 4.75	21		3		2
7	Potato tuber (pionnotes)		9	46 by 5	38		19	60 by 5.5	27	64 by 5.7	6	51 by 5.75	1
6	Wheat straw							56 by 5.25					
6	Nutrient agar		7		29		24	54 by 5.1	43		10		
40	Wheat kernels			35 by 4.25	43	43 by 4.5		49 by 4.75					
40	Rice		3	32 by 4.5	55	31 by 4.75	26	45 by 4.75	16				

TABLE I.—*Fluctuation of the average sizes of the conidial and perfect stages of Gibberella Saubinetii based on the average of 10 measurements*—Continued

PERFECT STAGE

Age of culture.	Pure culture on sterilized—	Height and diameter of perithecia.	Average size and percentage of equiseptate ascospores.					
			1-septate.		2-septate.		3-septate.	
Days.		μ	μ	*P. ct.*	μ	*P. ct.*	μ	*P. ct.*
10....	Potato stem	214 by 183	21 by 3.5	36	22 by 3.5	13	22 by 3.75	51
30....	Vicia faba stem	225 by 190					25 by 4	100
60....	do	200 by 170					29 by 4	100
60....	Wheat straw	178 by 120	15 by 4	9	18 by 4	5	18 by 4-25	86
40....	Cotton stem	245 by 230					24 by 4	100

Plate XIV contains illustrations from Gibberella, the original strain from a wheat kernel which failed to germinate. These kernels have a carmine color when the subcuticular plectenchyma (Pl. XIV, fig. *J*) is well developed. Red is formed as the basic modification of the fungus, while yellow is the acid modification, which can be observed on steamed rice in pure culture. *Fusarium subulatum*, *F. culmorum*, and *F. metachroum* have the same color shades and are also common on cereals, so that the red grains are not due alone to the presence of Gibberella. The perithecia of this fungus, being blue, as a rule, turn red brown with the addition of an alkali. On steamed potato tuber the conidia form a short-lived pionnotes, which is brownish white to ochreous, depending on the moisture and the influence of the carmine, which enters the conidia to some extent. The conidia of this pionnotes rapidly swell (Pl. XIV, fig. *H*), separate into cells, germinate, and produce new conidia (Pl. XIV, fig. *K*), which anastomose and form a stroma, while in the other species mentioned the conidia remain perfect, dry out, and are long-lived. It was interesting to note the increase of septa in germinating spores, which may have as many as 9 (Pl. XIV, fig. *H*), while the normal conidia (Pl. XIV, figs. *G* and *F*) have 3 to 5 septa. The ascospores swell (Pl. XIV, fig. *E*, 1) like the conidia, and this swelling often lasts even after desiccation. However, cultures on straw may develop a type of ascospores with a smooth outline (Pl. XIV, fig. *E*, 2) unless a rapid desiccation causes constriction between the septa (Pl. XIV, fig. *E*, 3). A hundred asci may be formed in one perithecium, but, as a rule, they are not so numerous. Typical paraphyses are seldom seen between the asci, but they are present (Pl. XIV, fig. *D*) and are 4 to 6 celled. Perithecia have two sizes of cells. Groups of large cells surround the ostiolum like a collar, which may or may not be pronounced (Pl. XIV, fig. *C*). Two such collars rarely seen in other perithecia (Pl. XIV, fig. *A*) proved the fact that sometimes two ostioli allow the ascospores to escape. The main body of the peridium is small celled, and the arrangement of the cells indicates their hyphal origin. A longitudinal section shows the peridium to consist of three layers (Pl. XIV, fig. *B*). The stroma of Gibberella is very

changeable. It may be reduced to a few hyphæ or formed as a thallus-like layer. On substrata, such as Robinia stems, a sphærostilbe-like stroma may be formed with a colony of perithecia at the top (Pl. XV, fig. *D*), or a short but compact stroma develops with a single perithecium (Pl. XV, fig. *G*) or a few together. The protuberancelike projections on the peridium are often not confined to the collar surrounding the neck or the ostiolum. They may develop on any place, especially when moisture allows a continuous growth beyond the time of maturity of the spores. These projections (Pl. XV, figs. *D* and *E*) resemble *Hypomyces ipomoeae*, but all stages from a verrucose to a smooth peridium (Pl. XV, fig. *F*) can be secured by selection of media and special methods of transfers in connection with various amounts of moisture. A larger stroma develops when mycelium is used in starting the culture on a cotton or Melilotus stem. But very few colonies of perithecia may appear with this method. Conidia and ascospores transferred to the same substratum will produce more numerous perithecia with less stroma. The illustrations in Plate XV, figures *D–G*, are made from Gibberella, the strain isolated from *Ipomoea batatas;* but the strain isolated from Triticum (Pl. XIV) corresponds in all respects with the sweet potato strain. In brief, these pure cultures show constancy in ascospores and conidia, but so much variation in the production of stroma and general appearance of perithecia that field material with such differences would be easily referred to more than one species, or even genus.

KEY TO THE SPECIES OF FUSARIUM DESCRIBED FROM PURE CULTURES GROWN IN DAYLIGHT

A. SPECIES OF FUSARIUM WITHOUT KNOWN PERFECT FORM

I. Terminal chlamydospores present.

a. Conidia cream-colored to brownish white, except in *Fusarium coeruleum* (Lib.) Sacc.; conidia not sharply pointed at the ends; foot and heel of the base reduced to a papilla-like appendage. No wine-red color on sterilized, watered rice. Section Martiella .....(Pl. XVI, fig. *K*) *Fusarium radicicola*, n. sp.

b. Conidia ochreous to salmon colored, except in *Fusarium redolens* Wollenw.; conidia with curved apical end constricted like a flask neck and with a pedicellate base, but without a prominent heel. A wine-red color, turning blue upon the addition of alkali on sterilized watered rice, except in *F. conglutinans* Wollenw. Section Elegans.

1. Sickle-shaped conidia; slender, about 11 to 13 times longer than broad.

a. Sporodochia absent, conidia mostly unicellular.
Fusarium orthoceras App. and Wollenw.

b. Sporodochia present; 3-septate conidia up to 100 per cent.

* Blue sclerotial plectenchymata effuse and few on sterilized potato tuber.
(Pl. XVI, fig. *N*) *Fusarium orthoceras*, var. *triseptatum*, n. var.

** Blue sclerotial plecten chymata small, convex, numerous on sterilized potato tuber.....(Pl. XVI, fig. *D*) *Fusarium batatatis*, n. sp.

2. Sickle-shaped conidia 8–9 times longer than broad.

a. Pionnotes reduced.....*Fusarium oxysporum* Schlecht.

b. Pionnotes perfect.....(Pl. XVI, fig. *F*) *Fusarium hyperoxysporum*, n. sp.

II. Terminal chlamydospores absent, conidia ochreous to salmon colored.
  a. Conidia with curved apical end constricted like a flask neck, heel of the pedicellate base not prominent. Section Discolor.
    1. Intercalated chlamydospores rare and not in clusters. No carmine color on sterilized potato tuber. (Pl. XVI, fig. *L*) *Fusarium incarnatum* (Rob.) Sacc.
    2. Intercalated chlamydospores occur singly and in cluster chains. A carmine color develops on sterilized potato tuber.
      (Pl. XVI, fig. *J*) *Fusarium culmorum* (W. G. Sm.) Sacc.
  b. Conidia with a prolongated and pointed apical end and with the heel of the pedicellate base prominent.
    1. Parabolic to hyperbolic curves prevail in conidia seen in side view. No carmine color on steamed potato tuber. Section Gibbosum.
      a. Apical end of conidia curved, subfiliform.
        (Pl. XVI, fig. *P*) *Fusarium caudatum*, var. *volutum*, n. var.
      b. Apical end of conidia curved, filiform.
        (Pl. XVI, fig. *M*) *Fusarium caudatum*, n. sp.

III. Terminal and intercalated chlamydospores absent. Conidia resemble those in the section Gibbosum, but hyperbolic curves are seldom pronounced. A carmine mycelium color on steamed potato tuber. Section Roseum.
  (Pl. XVI, fig. *G*) *Fusarium acuminatum* Ell. and Ev.

B. SPECIES OF FUSARIUM WITH KNOWN PERFECT FORM

1. Conidial stage similar to the section Martiella of the genus Fusarium, but with a subpedicellate base. Section Pseudomartiella of the genus Hypomyces.
  a. Conidia largely 3-septate. Perithecia averaging in size 350 to 450 by 275 to 375μ. Ascospores, 10 to 15 by 5 to 6.75μ.
    (Pl. XIII, fig. *J*) *Hypomyces cancri* (Rutg.) n. comb.
  b. Conidia largely 5-septate. Perithecia, 225 to 375 by 175 to 300μ. Ascospores, 10 to 13 by 4.5 to 6μ.
    (Pl. XVI, fig. *H*) *Hypomyces ipomoeae*, (Hals.) Wollenw.
2. Conidial stage similar to the section Discolor of the genus Fusarium, but chlamydospores absent. Genus Gibberella.
  (Pl. XVI, fig. *O*) *Gibberella Saubinetii* (Mont.) Sacc.

This key might have been based entirely upon the morphological characters and curvature of the conidia, but since the color reactions offer a simpler, though less trustworthy means of identification, they have been employed. The key, therefore, should be regarded only as an aid in identification, not as a guide to the morphology, which has been discussed in the diagnosis and illustrated in detail in the illustrations.

In Table II the average size of the various spore types has been given approximately to allow a survey of the differences between the species. The spore diameter is an important factor for the determination of species of Fusarium, as may be seen in comparing equiseptate conidia of *Fusarium culmorum* and *F. camptoceras*. The conidial length is less significant. The measurements of chlamydospores recorded are confined to their cross diameter, the two dimensions not varying much in the almost spherical unicellular spores. Ovoid and 2-celled spores have a major axis which consequently has a higher average length than the diameter of spherical spores shows in Table II.

The color range indicates that related species have similar colors of corresponding organs. The relations of color and reaction of organisms, studied also by Milburn (1904) and Bessey (1904), are constant under constant conditions. On substrata rich in carbohydrates many fungi and bacteria produce alkaline substances; on those rich in peptone, acid substances. Each reaction is accompanied by special colors, which change with the change of reactions of the substratum. Many fungi, however, forced to grow on very alkaline or acid media refuse to develop characteristic colors.

Table II, therefore, does not refer to artificially made acid or alkaline media, but to reactions developed by the fungi on potatoes, rice, and stems sterilized after the addition of water, but otherwise unchanged. The reaction of these media differs but slightly from neutral.

Blue perithecia of Gibberella turn red to brown, and carmine mycelium turns yellow with acids, but their original color redevelops by addition of sufficient alkali. This alternative change of color can be produced repeatedly. The yellow color on rice turns violet with alkali and redevelops yellow with acids. These relations between reaction and color are so constant that they facilitate the determination of many species and are also of value for the characterization of sections.

TABLE II.—*Some characters of the described species of Fusarium, with and without known ascus stage, occurring on sweet potato*

Name of fungus.	Section.	Perithecia.				Ascospores.				Average diameter of chlamydospores.	
		Presence or absence.	Color modification.		Average size.	Septation.	Shape.		Average size.	Mostly terminal and intercalated 1 to 2 cellular.	Mostly intercalated in chains and clusters.
			Basic.	Acid.			Ellipsoidal.	Fusoid-falcate.			
					μ				μ	μ	μ
Hypomyces ipomoeae (Hals.) Wollenw.	Pseudomartiella	*a* +	Red	Yellow	225 to 375 by 175 to 300	1	*a* +	*b* −	10 to 13 by 4.5 to 6	7 to 10	.....
Hypomyces cancri (Rutg.), n. comb.	.....	*a* +	Red	Yellow	350 to 450 by 275 to 375	1	*a* +	*b* −	10 to 15 by 5 to 6.75	7 to 10	.....
Gibberella Saubinetii (Mont.) Sacc.	.....	*a* +	Blue	Red	150 to 250 by 100 to 250	3	*b* −	*a* +	20 to 30 by 3.75 to 4.75	.....	.....
Fusarium acuminatum Ell. and Ev.	Roseum	*b* −	.....	.....	.....	.....	.....	.....	.....	.....	.....
Fusarium culmorum (W. G. Sm.) Sacc.	Discolor	*b* −	.....	.....	.....	.....	.....	.....	.....	.....	7 to 14
Fusarium incarnatum (Rob.) Sacc.	.....do	*b* −	.....	.....	.....	.....	.....	.....	.....	.....	7 to 14
Fusarium caudatum, n. sp.	Cibbosum	*b* −	.....	.....	.....	.....	.....	.....	.....	.....	7 to 14
Fusarium caudatum, var. volutum, n. var.	.....do	*b* −	.....	.....	.....	.....	.....	.....	.....	.....	7 to 14
Fusarium orthoceras App. and Wollenw.	Elegans	*b* −	.....	.....	.....	.....	.....	.....	.....	7 to 10	.....
Fusarium orthoceras triseptatum, n. var.	.....do	*b* −	.....	.....	.....	.....	.....	.....	.....	7 to 10	.....
Fusarium batatatis, n. sp.	.....do	*b* −	.....	.....	.....	.....	.....	.....	.....	7 to 10	.....
Fusarium oxysporum Schlecht.	.....do	*b* −	.....	.....	.....	.....	.....	.....	.....	7 to 10	.....
Fusarium hyperoxysporum, n. sp.	.....do	*b* −	.....	.....	.....	.....	.....	.....	.....	7 to 10	.....
Fusarium radicicola, n. sp.	Martiella	*b* −	.....	.....	.....	.....	.....	.....	.....	7 to 10	.....

a +, Present. *b* −, Absent.

TABLE II.—*Some characters of the described species of Fusarium, with and without known ascus stage, occurring on sweet potato*—Continued

Name of fungus.	Characteristic color.				Conidia.					
	Blue sclerotial plectenchymata.	Modification of plectenchymatic mycelium.		Conidia in masses.	Normal septation.	Average size of 3-septate conidia.	Maximal percentage of normal equiseptate conidia.			Average size of 5-septate conidia.
		Basic.	Acid.				3-septate.	4-septate.	5-septate.	
						μ				μ
Hypomyces ipomoeae (Hals.) Wollenw.	*b* −	Olive green to brown	Red.....	Brownish white...	5 (3 to 5)	30 to 45 by 3.75 to 5.....	60	35	100	45 to 70 by 4.25 to 5.5.
Hypomyces cancri (Rutg.), n. comb.	*b* −	.....do.....	...do.....	.....do.....	3 (3 to 5)	30 to 45 by 3.75 to 5.....	100	50	30	45 to 55 by 4.25 to 5.5.
Gibberella Saubinetii (Mont.) Sacc.	*b* −	Red.....	Yellow	Ochreous to salmon.	3 to 5	30 to 45 by 4.25 to 5.....	100	25	100	45 to 60 by 4.75 to 5.5.
Fusarium acuminatum Ell. and Ev.	*a* +	.....do.....	...do.....	Orange.....	5	20 to 45 by 2.75 to 4.25...	15	35	100	40 to 70 by 3 to 4.5.
Fusarium culmorum (W. G. Sm.) Sacc.	*b* −	.....do.....	...do.....	Ochreous to salmon.	5	25 to 35 by 5 to 6.....	30	30	100	30 to 45 by 5.5 to 7.
Fusarium incarnatum (Rob.) Sacc.	*b* −	Brown.....	Brown..	.....do.....	3 to 5	20 to 25 by 3.5 to 4.5.....	100	20	100	30 to 50 by 3.75 to 5.
Fusarium caudatum, n. sp.....	*b* −	.....do.....	...do.....	.....do.....	5	25 to 35 by 2.75 to 4.....	10	25	100	40 to 80 by 3 to 4.5.
Fusarium caudatum, var. volutum, n. var.	*b* −	.....do.....	...do.....	.....do.....	3 (3 to 5)	25 to 35 by 2.5 to 3.75....	100	50	30	30 to 50 by 3 to 4.
Fusarium orthoceras App. and Wollenw.	*b* −	Blue.....	Red.....	.....do.....	0 (3)	25 to 46 by 3.25 to 4.....	15	3	1	40 to 50 by 3.25 to 4.
Fusarium orthoceras triseptatum, n. var.	*b* −	.....do.....	...do.....	.....do.....	3 (0)	25 to 45 by 2.75 to 4.....	100	20	8	40 to 50 by 3.25 to 4.
Fusarium batatatis, n. sp.....	*a* +	.....do.....	...do.....	.....do.....	3	25 to 45 by 2.75 to 4.....	100	25	16	40 to 50 by 3 to 4.
Fusarium oxysporum Schlecht..	*a* +	.....do.....	...do.....	.....do.....	3	25 to 40 by 3.25 to 4.5....	100	25	10	32 to 42 by 3.5 to 4.75.
Fusarium hyperoxysporum, n. sp.	*a* +	.....do.....	...do.....	.....do.....	3	25 to 40 by 3.25 to 4.5....	100	25	10	32 to 42 by 3.5 to 4.75.
Fusarium radicicola, n. sp.....	*b* −	Olive green to brown	...do.....	Brownish white...	3	30 to 45 by 3.75 to 5.....	100	30	5	40 to 50 by 4 to 5.25.

a +, Present. *b* −, Absent.

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SUMMARY

(1) Only 2 out of 11 species and 2 varieties of Fusarium on sweet potato (*Ipomoea batatas* Poir.) developed the perfect form: *Hypomyces ipomoeae* (Hals.) Wollenw. [= *Nectria ipomoeae* Hals. = *Creonectria ipomoeae* (Hals.) Seav.] and *Gibberella Saubinetii* (Mont.) Sacc.

(2) The other species of Fusarium on sweet potato remain in the genus Fusarium Lk., and belong to the sections Martiella, Elegans, Discolor, Gibbosum, and Roseum.

(3) *Fusarium orthoceras* App. and Wollenw., *F. oxysporum* (Schlecht.), *F. incarnatum* (Rob.) Sacc., *F. culmorum* (W. G. Sm.) Sacc., and *F. acuminatum* Ell. and Ev. are common but not obligate sweet-potato fungi. The first two are especially prevalent. These five are also found on Solanum and other hosts. *F. oxysporum* is proved a cause of wilt disease of Solanum, but not of Ipomoeae.

(4) *Fusarium batatatis* Wollenw. and *F. hyperoxysporum* Wollenw. causing wilt disease on Ipomoea (according to Harter and Field) are species of the section Elegans. The former is related to *F. orthoceras*, the latter to *F. oxysporum*.

(5) *Fusarium culmorum* (W. G. Sm.) Sacc., synonym of *F. rubiginosum* App. and Wollenw., occurs more often on cereals, especially Triticum, than on Ipomoea and Solanum.

(6) Species of Fusarium described as new: *F. radicicola; F. orthoceras*, var. *triseptatum; F. batatatis; F. hyperoxysporum; F. caudatum;* and *F. caudatum*, var. *volutum*.

(7) New combination: *Hypomyces cancri* (Rutg.), n. comb. (= *Nectria cancri* Rutg.).

LITERATURE CITED

1879. Reinke, Johannes, and Berthold, Gottfried. Die Zersetzung der Kartoffel durch Pilze. p. 26–39, pl. 1–2. Berlin. *See* Unters. Bot. Lab. Univ. Göttingen, Heft 1.

1879. Saccardo, P. A. Fungi Gallici lecti a cl. viris P. Brunaud, C. C. Gillet et Abb. Letendre. *In* Michelia, v. 1, no. 5, p. 500–538.

1884. Smith, W. G. Diseases of Field and Garden Crops, chiefly such as caused by Fungi. 353 p., 143 fig. London.

1886. Wahrlich, Woldemar. Beitrag zur Kenntniss der Orchideenwurzelpilze. *In* Bot. Ztg., Jahrg. 44, No. 28, p. 481–488; No. 29, p. 497–505. pl. 3. Also reprinted.

1890. Sorokine, Nicolas. Ueber einige Krankheiten der Kulturpflanzen im Süd-Ussurischen Gebiet. (Russian.) 32 p., 1 pl. Kazan. (Trudy Obshch. Estestv. I. Kazansk. Univ., t. 22, vyp. 3.)

1892. Halsted, B. D. The egg-plant stem rot. (Nectria ipomoeae, Hals.) *In* N. J. Agr. Exp. Sta., 12th Ann. Rpt., 1891, p. 281.

1896. Ellis, J. B., and Everhart, B. M. New species of fungi from various localities. *In* Proc. Acad. Nat. Sci. Phila., 1895, p. 441.

1897. Mattirolo, Oreste. Il genere Cerebella di Vincenzo Cesati: richerche intorno al suo sviluppo e alla sua sistemazione. *In* Mem. R. Accad. Sci. Ist. Bologna, s. 5, t. 6, p. 663–684, 1 pl.

1898. Selby, A. D. Some diseases of wheat and oats. *In* Ohio Agr. Exp. Sta., Bul. 97, p. 40–42, fig. 4.

1899. McALPINE, DANIEL. Fungus Diseases of Citrus Trees in Australia, and their Treatment. 132 p., 31 pl. Melbourne.

1899. SACCARDO, P. A. Sylloge Fungorum . . . v. 14, p. 1125–1126. Patavii.

1901. DELACROIX, GEORGES. La maladie des œillets d'Antibes. *In* Ann. Inst. Nat. Agron., no. 16, p. 161–201, 11 fig.

1901. ZIMMERMANN, ALBRECHT. Ueber einige an tropischen Kulturpflanzen beobachtete Pilz. I. *In* Centbl. Bakt. [etc.], Abt. 2, Bd. 7, No. 3, p. 101–106, 8 fig.

1904. BESSEY, E. A. Über die Bedingungen der Farbbildung bei Fusârium. *In* Flora, Bd. 93, Heft 4, p. 301–334. Also reprinted.

1904. MILBURN, THOMAS. Ueber Aenderungen der Farben bei Pilzen und Bakterien. *In* Centbl. Bakt. [etc.], Abt. 2, Bd. 13, No. 5/7, p. 129–138; No. 9/11, p. 257–276, 6 fig., 2 pl.

1904. SHELDON, J. L. A corn mold (Fusarium moniliforme, n. sp.). *In* Nebr. Agr. Exp. Sta., 17th Ann. Rpt., [1903], p. 23–32, illus.

1904. ZIMMERMANN, ALBRECHT. Untersuchungen über tropische Pflanzenkrankheiten. *In* Ber. Land- u. Forstw. Deutsch-Ostafrika, Bd. 2, Heft 1, p. 11–36, pl. 3, fig. 16.

1905. PAMMEL, L. H. Some fungus diseases common in Iowa during the season of 1904. *In* Proc. 26th Ann. Meeting, Soc. Prom. Agr. Sci., p. 69–82.

1905. YOSHINO, K. List of fungi found in the Province of Higo. *In* Tokyo Bot. Mag., v. 19, no. 224, p. 208 (Japanese).

1909. SELBY, A. D., and MANNS, T. F. Studies in diseases of cereals and grasses. Ohio Agr. Exp. Sta., Bul. 203, p. 187–236, illus.

1910. APPEL, OTTO, and WOLLENWEBER, H. W. Grundlagen einer Monographie der Gattung Fusarium (Link.). *In* Arb. Biol. Anst. f. Land- u. Forstw., Bd. 8, Heft 1, p. 1–207, 10 fig., 3 pl.

1911. ——— ——— Studien über die Gattung Fusarium (Link.). *In* Mitt. Biol. Anst. f. Land- u. Forstw., Heft 11, p. 17–20.

1911. WOLLENWEBER, H. W. Untersuchungen über die natürliche Verbreitung der Fusarien an der Kartoffel. *In* Mitt. Biol. Anst. f. Land- u. Forstw., Heft 11, p. 20–23.

1912. JACZEWSKI, A. DE. Quelques nouvelles espèces de Fusarium sur céréales. *In* Bul. Soc. Mycol. France, t. 28, fasc. 4, p. 340–348, 4 fig.

1912. VOGES, ERNST. Zur Fusskrankheit des Getreides. *In* Deut. Landw. Presse, Jahrg. 39, No. 71, p. 815–816, 4 fig.; No. 72, p. 823–824, 3 fig.

1912. WIGHT, C. J. A stem rot disease of carnations due to a species of Fusarium. *In* Pomona Col. Jour. Econ. Bot., v. 2, no. 3, p. 315–336, 4 pl.

1913. RUTGERS, A. A. L. The Fusariums from cankered cacao-bark and Nectria cancri nova species. *In* Ann. Jard. Bot. Buitenzorg, v. 27 (s. 2, v. 12), pt. 1, p. 62–63, pl. 11, fig. 2–4.

1913. SCHAFFNIT, E. Der Schneeschimmel und die übrigen durch Fusarium nivale Ces. hervorgerufenen Krankheitserscheinungen des Getreides. *In* Landw. Jahrb., Bd. 43, Heft 4, p. 520–648, 5 pl.

1913. VOGES, ERNST. Der Schneeschimmel. *In* Deut. Landw. Presse, Jahrg. 40, No. 19, p. 229–231, fig. 231–233.

1913a. WOLLENWEBER, H. W. Pilzparasitäre Welkekrankheiten der Kulturpflanzen. *In* Ber. Deut. Bot. Gesell., Bd. 31, Heft 1, p. 17–34.

1913b. ——— Ramularia, Mycosphaerella, Nectria, Calonectria. Eine morphologisch pathologische Studie zur Abgrenzung von Pilzgruppen mit cylindrischen und sichelförmigen Konidienformen. *In* Phytopathology, v. 3, no. 4, p. 197–242, pl. 20–22.

1913c. ——— Studies on the Fusarium problem. *In* Phytopathology, v. 3, no. 1, p. 24–50, 1 fig., pl. 5.

1914. JOHNSON, E. C. A study of some imperfect fungi isolated from wheat, oat, and barley plants. *In* Jour. Agr. Research, v. 1, no. 6, p. 475–489, pl. 62–63.

PLATE XII

Fig. A.—*Fusarium batatatis*, n. sp.: Mycelium stage with blue sclerotial plectenchymata on steamed potato tuber.

Fig. B.—*Fusarium batatatis*, n. sp.: Ochreous- to salmon-colored pionnotes on the same medium, but from a transfer of a single sickle-shaped conidium.

Fig. C.—*Fusarium batatatis*, n. sp.: Wine-red acid color modification of the fungus on steamed rice, turning blue with alkali.

Plate XII was reproduced from paintings made by Mr. J. M. Shull from 10-day-old test-tube cultures of the fungus.

A B C

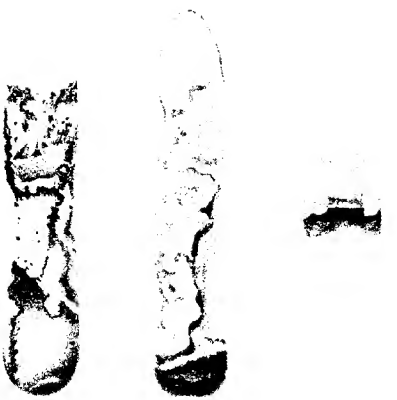


PLATE XIII

Figs. A-G.—*Hypomyces ipomoeae* (Hals.) Wollenw. Fig. H.—*Fusarium incarnatum* (Rob.) Desm. Fig. J.—*Hypomyces cancri* (Rutg.), n. comb. The drawings of *H. ipomoeae* were made from subcultures on moist wheat heads of a strain isolated by Dr. Reddick, Cornell University Experiment Station, from a badly rotted sweet potato (*Ipomoea batatas*), sent him from Wooster, Ohio, on April 30, 1907, by J. M. van Hook of the Ohio State Agricultural Experiment Station. *F. incarnatum* is illustrated from a strain isolated from sweet potato.

Fig. A.—*Hypomyces ipomoeae*. Ascospores: 1, Ellipsoidal shape; 2, form of a double paraboloid; 3, overripe, slightly swollen stage; 4, separation of the two cells in overripe stage. × 1,000.

Fig. B.—*Hypomyces ipomoeae*. Asci with a paraphysis. × 500.

Fig. C.—*Hypomyces ipomoeae*. Perithecium. × 200.

Fig. D.—*Hypomyces ipomoeae*. Chlamydospores: 1 and 3, lateral; 2, intercalated and terminal; 4, intercalated within a conidium (conidiochlamydospore). × 1,000.

Fig. E.—*Hypomyces ipomoeae*. Perithecium formed by spiral coiling of a lateral hypha. × 500.

Fig. F.—*Hypomyces ipomoeae*. False conidial heads produced at the end (1) of conidiophores by spores suspended in drops of water. The conidiophore sprang from an old conidium which was separated into two parts, one of which was dead (*a*). × 500.

Fig. G.—*Hypomyces ipomoeae*. Normal conidia: 1, More curved at the ends than the other spores; 2–7, tri- to quinque-septate spores.

Fig. H.—*Fusarium incarnatum* (Rob.) Desm.: Conidia, *a*, short, *b*, slender; 1–3, normal 5-septate conidia; 4, lanceolate; 5, exceptionally large; *c*, pedicellate base without heel.

Fig. J.—*Hypomyces cancri* (Rutg.), n. comb.: Mature conidia, the first one (1) being especially large.

PLATE XIV

Gibberella Saubinetii (Mont.) Sacc. This fungus was isolated from a wheat kernel in Dahlem, near Berlin, Germany. The first perithecia appeared in pure cultures after several transfers to fresh media. Thus far no differences have been observed between the wheat and the sweet-potato strains.

Figs. A–C.—*Gibberella Saubinetii:* Perithecia grown in pure culture; A, on stem of *Vicia faba*, with two ostiola surrounded by a collar of large peridial cells; B, on wheat grains showing the ascus ball after one-half of the peridium had been lifted by a longitudinal section; C, on Irish potato stem, without a distinct collar. × 200.

Fig. D.—*Gibberella Saubinetii:* Two asci with a paraphysis. ×500.

Fig. E.—*Gibberella Saubinetii:* Ascospores, 1, with slightly swollen cells, overripe; 2, normal shape; 3, dried condition. ×1,000.

Fig. F–G.—*Gibberella Saubinetii:* Normal conidia grown on Irish potato stem. F, 12 days old; G, 6 days old, culture watered more, therefore the conidia are broader than in figure F. ×1,000.

Fig. H.—*Gibberella Saubinetii:* Abnormally multiseptate conidium about to germinate. These conidia are frequently to be found with swollen cells in young, and sometimes old cultures on the parenchyma of potato tubers. (Compare fig. K.) ×1,000.

Fig. J.—*Gibberella Saubinetii:* Plectenchymatic parts of a stroma, formed by closely interwoven chains of swollen cells which have a thick membrane and brown to red contents with many vacuoles. Not to be confused with true chlamydospores, although very resistant to unfavorable conditions.

Fig. K.—*Gibberella Saubinetii:* A number of conidia formed in young cultures on the moist surface of potato cylinders. Septation (1, 3) and shape (2) rarely normal; 4, mother conidium broken into two halves (a, b), both of which have developed some small conidiophores from the cells torn asunder. ×500.

PLATE XV

Fig. A.—*Hypomyces ipomoeae* (Hals.) Wollenw.: Sweet-potato strain, its perithecial stage isolated in 1907 by Dr. Donald Reddick, Cornell University Experiment Station. (See legend of Pl. XIII.) 1, 2, Grown in pure culture on cotton stem; 3, on maple stem; 4, on wheat straw; 5 and 6, on potato cylinder. ×50.

Fig. B–C.—*Hypomyces cancri* (Rutg.), n. comb.: The hemp strain found with perithecia on a dead taproot of hemp at the soil level, Potomac Flats, Washington, D. C., 1912. The perithecia and ascospores are larger, but the conidia are less septate than those of the sweet potato strain. B, Grown on steamed corn kernels. C, 1, Perithecia from the original field material; C, 2, 3, Grown in pure culture on cotton stem. ×50.

Fig. D–G.—*Gibberella Saubinetii* (Mont.) Sacc.: The mycelium stage was isolated in 1912 from sweet-potato tubers by Mr. C. A. Ludwig, Lafayette, Ind. The writer obtained perithecia after the second transfer of conidia on cotton stem, wheat straw and heads, potato stem, etc. The first perithecia appeared gregarious on a coremium-like or irregular plectenchymatic stroma. D, Grown on stem of Robinia, which was more or less reduced when single ascospores of these perithecia were transferred to fresh moist steamed stems of plants; F and G, grown on cotton stem (on almost dry wheat straw the stroma could be reduced still more and completely disappeared in some of the later cultures on this medium); E, grown on wheat straw.

PLATE XVI

Fusarium spp. on sweet potato with and without known perfect stage, grown on sterilized vegetables.

Fig. A-E.—*Fusarium batatatis*, n. sp.: A, Microconidia. ×1,000. B, 1, Intercalated and terminal chlamydospores. 2, In young stage. 3, Branch from sclerotial plectenchymata, therefore no true chlamydospores. 4, Chlamydospores formed from the content of conidial cells (conidio-chlamydospores). 5, Mature chlamydospores. ×500. C, Two conidia anastomosing, one of them producing microconidia. ×500. D, Normal conidia from sporodochia. ×1,000. E, Conidiophore from a sporodochium. ×500.

Fig. F-P.—Characteristic conidia of different species of Fusarium. ×1,000.

Fig. F.—*Fusarium hyperoxysporum*, n. sp.

Fig. G.—*Fusarium acuminatum* Ell. and Ev.

Fig. H.—*Hypomyces ipomoeae* (Hals.) Wollenw.

Fig. J.—*Fusarium culmorum* (W. G. Sm.) Sacc.

Fig. K.—*Fusarium radicicola*, n. sp.

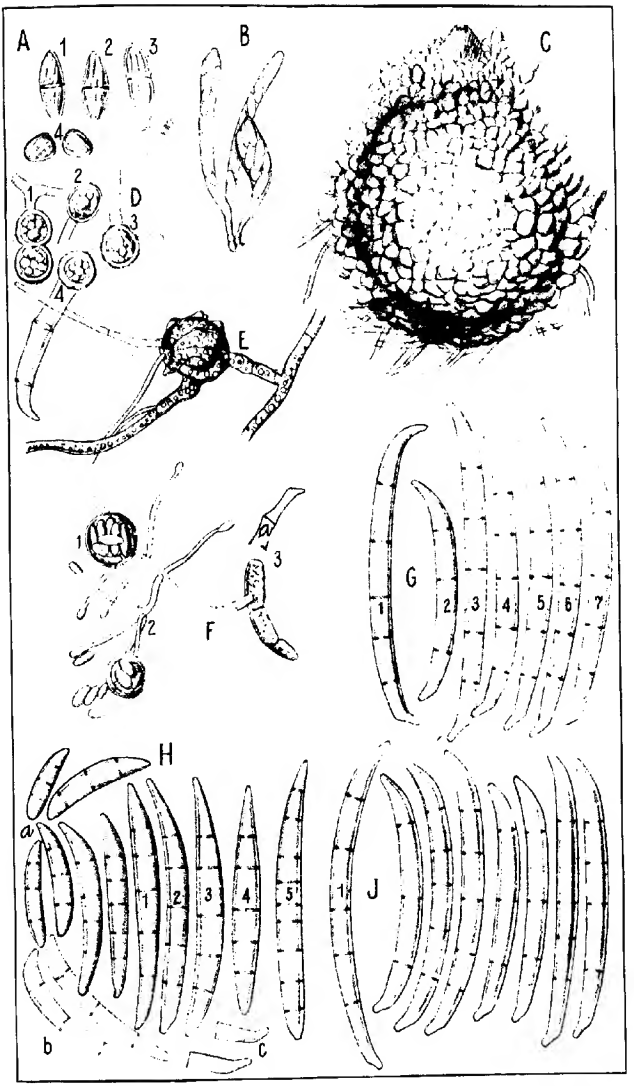
Fig. L.—*Fusarium incarnatum* (Rob.) Sacc.

Fig. M.—*Fusarium caudatum*, n. sp.

Fig. N.—*Fusarium orthoceras* var. *triseptatum*, n. var.

Fig. O.—*Gibberella Saubinetii* (Mont.) Sacc.

Fig. P.—*Fusarium caudatum* var. *volutum*, n. var.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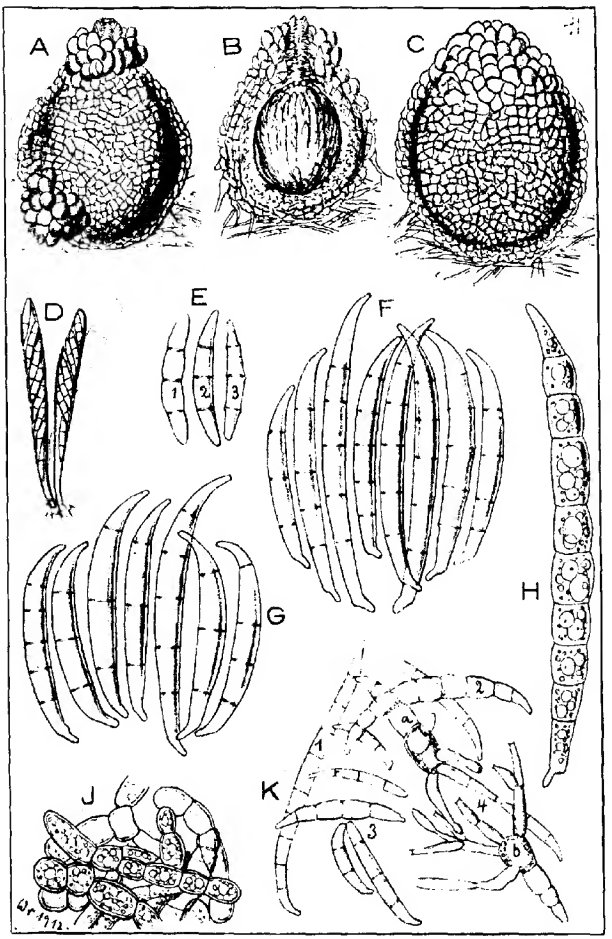
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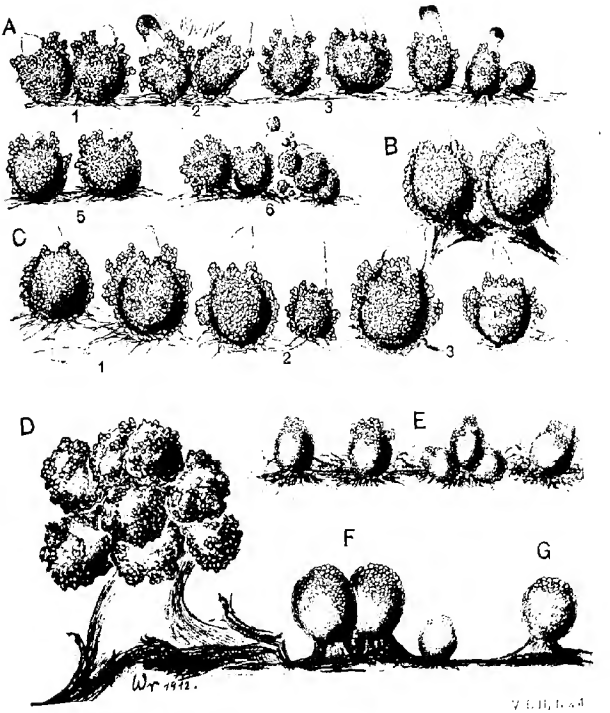
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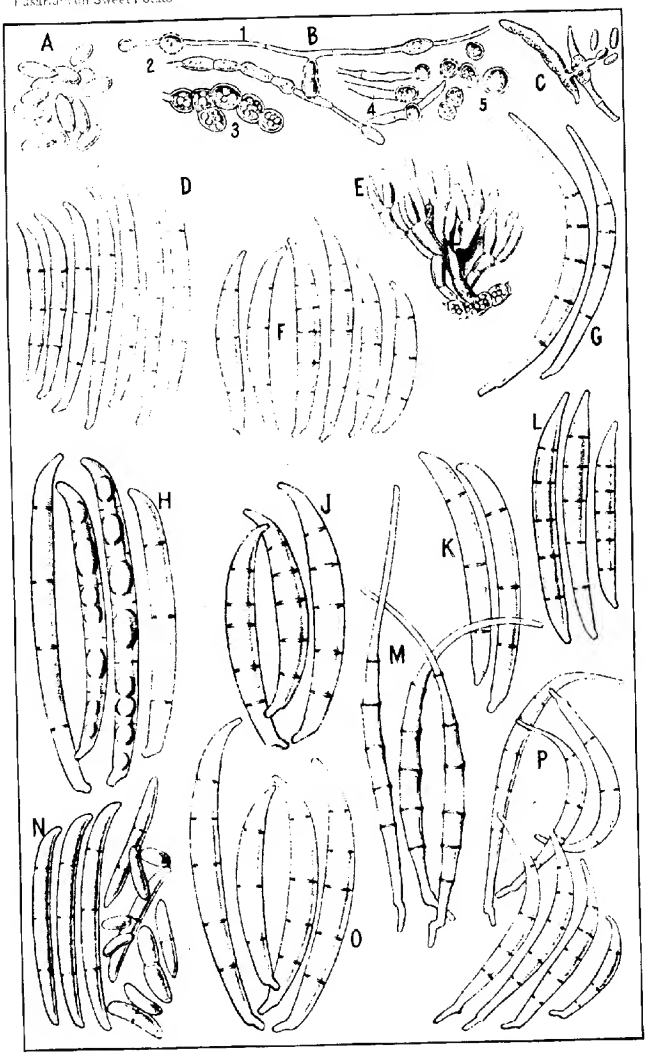
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MUTATION IN EGYPTIAN COTTON

By THOMAS H. KEARNEY,
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INTRODUCTION

The occurrence of saltatory or discontinuous variations has frequently been reported by breeders of plants. Most of the instances mentioned in the older literature were not supported by unimpeachable evidence, but in the aggregate they established a strong presumption of the reality of this type of variation. Recent investigation has led to a better understanding of the phenomenon, which is now generally known as mutation.[1]

The publication of De Vries's work "Die Mutationstheorie" (1901–1903)[2] focused the attention of biologists upon the phenomenon of mutation by suggesting that it is not confined to domesticated organisms, but is also met with among wild species, and that organic evolution has taken place through the natural selection of mutations rather than of minor variations. While De Vries's theory of evolution has not won general acceptance, great interest attaches to his discovery of a plant in which mutation is a frequent rather than an extremely rare occurrence and from which numerous distinct and regularly heritable forms capable of description as elementary species or biotypes have been thus derived during a short period of time.

Among seed-propagated crop plants[3] there have been few well-substantiated instances of the origin by mutation of varieties which differ in several characters from the parental type, although their apparent rarity is perhaps attributable to imperfect knowledge of the history of

[1] Mutation in plants may be defined as a type of variation manifesting itself in the sudden appearance of a distinctly different individual the characters of which are uniformly expressed by its descendants when self-pollinated or cross-pollinated only among themselves.

This definition, which applies only to the higher plants, is purposely worded so as to exclude reference to the cause of mutation and to the conditions under which it takes place. Johannsen (1913, p. 161) has defined mutation as a sudden, discontinuous alteration of the biotype, independent of all crossing. This limitation of the term seems ill-advised, because it leaves us without a designation for the well-known cases which most biologists regard as the best examples of mutation and which represent a distinct and important phenomenon, although probably to be interpreted as resulting from remote or complex hybridization.

[2] Bibliographic citations in parentheses refer to "Literature cited," p. 301.

[3] "It must not be forgotten that the agricultural improved races do not possess the constancy of true species; whereas the varieties and subspecies of the horticulturist can only be distinguished from true species historically and systematically—not experimentally * * * In horticulture varieties arise by mutations, and varieties are elementary species. In agriculture, according to the current view and excepting in the instances of the unconscious isolation of elementary species, the highly improved races arise gradually through selection, but they never become species." (De Vries, 1909, v. 1, p. 82.)

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varieties in these groups.[1] Evidence is presented in this paper which is believed to justify the conclusion that mutation occurs in Egyptian cotton and that numerous varieties have thus arisen in Egypt and in Arizona.

Many biologists hold that mutation as observed by De Vries is an after-effect of hybridization. The mutability of Egyptian cotton is capable of a similar explanation, for it is widely believed that the type as a whole originated as a hybrid. It can at least be shown that the varieties now grown in Egypt, including the one which has given rise to the Arizona varieties, have been constantly exposed to crossing among themselves and with other types of cotton.

The breeder who works with a mutable group of plants has a great advantage in the ease with which new varieties can be fixed. It has been possible to maintain a high degree of uniformity in the varieties of Egyptian cotton which have arisen in Arizona by keeping each new form isolated from other types of cotton and by removing the relatively few aberrant plants from the seed increase fields before they come into blossom. In Egypt the maintenance of the cotton industry has largely depended upon the successive appearance of desirable mutants, since until very recently no adequate measures were taken to preserve a pure seed supply and each new variety rapidly deteriorated as a result of cross-pollination. While under the Arizona conditions deterioration is likely to be less rapid, the tendency of this type of cotton to produce an occasional valuable mutant may be regarded as a form of insurance against the possible "running out" of the present varieties.

The subjects treated in the following pages are: (1) The origin of Egyptian cotton, so far as it throws light upon the heterogeneous nature of this type and thus affords a possible explanation of its mutability; (2) the evidence for the mutational origin of the several varieties now grown commercially in Egypt; (3) the better known history of the Arizona varieties and the reasons for concluding that they have arisen by mutation, and (4) the evidence afforded by Egyptian cotton that mutability may be a result of hybridization.

The photographs used in illustrating this paper were made by Messrs. C. B. Doyle and Bruce Gilbert, of the Office of Acclimatization and Adaptation of Crop Plants and Cotton Breeding, Bureau of Plant Industry.

[1] There is some evidence that mutation occurs in tobacco. Mr. A. D. Shamel believes that the "Halliday" variety originated in this manner, although East and Hayes (1914) claim to have obtained an identical form in the F_2 of a Sumatra × Havana cross and consider it to represent merely a Mendelian recombination of the characters of the parent types. On the other hand, these authors (1914, p. 45) state that in tobacco "mutations may occur. We have shown the origin of one family by a very wide mutation. In this particular case it was not difficult to show that a constitutional change took place in a single germ cell of the mother plant."

A presumable case of mutation in barley has recently been described by L. Kiessling (1912).

ORIGIN OF THE EGYPTIAN VARIETIES

Although less than 100 years have elapsed since Egyptian cotton was first recognized as a distinct type, there is much uncertainty about its origin. It is known that two or more species of Gossypium were cultivated in Egypt early in the nineteenth century. One of these, *G. vitifolium* Lam. (?), was a brown-linted tree cotton which resembled the Peruvian type. Another was the American Sea Island cotton (*G. barbadense* L.).

According to Prof. Balls (1912, p. 3–4) these species soon hybridized. Among the resulting recombinations was the low growing, brown-linted Ashmuni variety. The Mit Afifi was selected out of the latter in 1887, "and from this now degenerate complex of sub-varieties and splitting-forms other varieties have been selected." This view of the origin of the type is sustained by Mr. Frederic Fletcher (1908, p. 382), who states: "We have then in Delile's plant, *G. vitifolium* Lam. (and Cav.), the parent that mated with Sea Island cotton to form our present crop."[1]

The evidence seems conclusive that more than one species of Gossypium has contributed to the formation of the Egyptian type of cotton as we know it to-day. There can, at least, be no reasonable doubt that since the beginning of commercial cotton growing in Egypt the conditions have been and still are favorable to interspecific hybridization. Sea Island and American Upland cottons have been introduced from time to time, and the botanically very distinct "Hindi" cotton (referred doubtfully by Watt to *Gossypium punctatum* Sch. and Thon.) is almost everywhere present[2] and hybridizes with the Egyptian plants. Until very recently the importance of preventing crossing has been quite unappreciated in Egypt, and the only remedy for the rapid deterioration of the varieties has been the development of new ones.

The appearance about the year 1850 of the Ashmuni variety marks the close of the first period in the evolution of the Egyptian type of cotton. This brown-linted cotton was quickly recognized as representing a new commercial type, quite distinct from any cotton previously known in the markets of the world. Although formerly grown in the Nile Delta, the Ashmuni variety is now confined to the region south of Cairo. Its place in lower Egypt has been taken by the Mit Afifi and by other varieties derived from the latter. According to Balls (1912, p. 106) "Afifi was introduced commercially about 1887, Abbassi in 1893, Yannovitch in 1899, Nubari in 1907, Sakel in 1909, and Assili in 1910." Numerous other varieties have arisen from time to time, but either failed to attain much commercial importance or have been supplanted by other sorts.

[1] The extreme complexity of the botany of Egyptian cotton is apparent from the treatment of the subject by Watt (1907, p. 214, 223, 256, 292).

[2] Mr. O. F. Cook (1911) found Hindi plants in nearly every field which he inspected in Egypt, the proportion ranging from 1 to 20 per cent of the total number of plants.

While little is accurately known of the origin of most of these varieties, the evidence seems to Prof. Balls (1912, p. 105) to justify the conclusion that "the majority probably arose as single-plant 'selections.' In the case of Yannovitch this is definitely known."

The impression prevails in Egypt that these varieties can scarcely be distinguished from one another except in yield and lint percentage, in adaptability to particular soils and climatic conditions, and in the length, color, and fineness of the fiber. Nevertheless, when grown in Arizona from imported seed, most of them could readily be distinguished even in the blossoming period, or at the latest after the first bolls were set. In characterizing them, however, it was necessary to ignore the numerous hybrids with Hindi cotton which appeared in most of the plantings.

As compared with the Mit Afifi, the Ashmuni produced lower and more bushy plants. The Abassi variety had remarkably long and pointed, relatively slender bolls, very different from the plump, short-pointed bolls of the Mit Afifi (Pl. XXV, fig. 1). The Yannovitch plants averaged taller than the Mit Afifi, but there was so much variation among the plants grown from imported seed of this variety that a close comparison was impracticable. The Nubari variety differed from the Mit Afifi in its more compact habit of growth, in its larger, more frequently 5-lobed leaves, in having the bracts of the involucre (Pl. XXII, fig. 1) more grown together at the base, and in the much longer, more tapering bolls. The Sakellaridis differed from the Mit Afifi variety in many of its characters, notably in the much larger proportion of deeply 5-lobed leaves, involucral bracts with long teeth which extended nearly to the base of the bracts, and conical, very abruptly and very sharply pointed bolls (Pl. XXV, fig. 4). In the habit of growth, in the shape and small size of the leaves, and in the shape of the bolls the Sakellaridis variety showed some resemblance to Sea Island cotton.

The conclusion that these varieties originated by mutation is supported by the following facts: (1) The derivation of each from a single plant discovered in a field of very different cotton; (2) the distinctness of their botanical characters, especially in the recently developed Nubari and Sakellaridis varieties; and (3) their tendency to remain uniform, which is, however, finally nullified by the ample opportunities afforded in Egypt for cross-pollination with other types and for the mixing of seeds at the gins.

ORIGIN OF NEW VARIETIES IN ARIZONA

Twelve years ago seed of the Mit Afifi variety, imported from Egypt, was planted at Yuma, Ariz. The resulting plants were generally unproductive, late in ripening, and produced fiber of poor quality. Selection carried on for several years resulted in some improvement in these respects, but the progress was not very encouraging. Although the plants showed considerable fluctuation, until 1908 there was no clear evidence that any of them had exceeded the limits of the characters of the Mit Afifi variety.

In that year two among the progeny rows were totally different in type from the parent variety and from one another. The characters of each were uniformly expressed in all plants of the row,[1] except the few and very different individuals which were obviously first-generation hybrids of Egyptian with Upland cotton. These two rows gave rise to the Yuma and Somerton varieties, described in an earlier publication (Kearney, 1910). Since both varieties appeared suddenly and were very uniform from the beginning when protected from cross-pollination with other types, the conclusion seems warranted that they were of mutational origin.

The Yuma variety was subjected during several years to yield tests and to mill tests, which showed the variety to be satisfactory in productiveness and in the spinning quality of the fiber. When a sufficient supply of pure seed had been obtained by carefully roguing the fields during three successive seasons, it was distributed to farmers in the Salt River Valley, Arizona, where this variety is now being grown on a commercial scale.[2]

Although the Somerton variety produced excellent fiber it was discarded because of its lateness in maturing and the excessive development of the vegetative branches.

Two other varieties, believed to be also of mutational origin, have since been developed in Arizona. They are here described under the names "Pima" and "Gila."

The contrasting characters of the Yuma, Pima, and Gila varieties are summarized in Table I.

TABLE I.—*Characters which distinguish the Yuma, Pima, and Gila varieties of Egyptian cotton*

Character.	Variety.		
	Yuma.	Pima.	Gila.
Vegetative branches.	Large, developing rapidly (Pl. XVIII, fig. 1).	Small, developing slowly or entirely wanting (Pl. XVIII, fig. 2).	Smaller than in the Yuma variety and developing less rapidly (Pl. XVIII, fig. 3).
Leaves of main stem.	A large proportion 5-lobed (Pl. XIX).	Usually deeply 5-lobed (Pl. XX).	Usually 3-lobed, when 5-lobed the basal lobes inconspicuous (Pl. XXI).
Involucres.	Bracts usually much longer than wide, strongly connate (Pl. XXII, fig. 2).	Bracts not much longer than wide, separate or nearly so (Pl. XXIII, fig. 1).	Bracts not much longer than wide, separate or nearly so (Pl. XXIII, fig. 2).
Bolls	About twice as long as wide, tapering from near the base, not sharply pointed, deeply pitted (Pl. XXIV, fig. 2).	Nearly twice as long as wide, less tapering and more sharply pointed than in Yuma, shallow pitted (Pl. XXIV, fig. 3).	Considerably less than twice as long as wide, abruptly contracted at the blunt apex, deeply pitted (Pl. XXV, fig. 2).
Average length of fiber.	About 1 1/2 inches	1 5/8 to 1 3/4 inches	About 1 7/8 inches.

[1] Some of the distinctive characters of each type were noted in the parent individual of the preceding year, but in neither case was it then recognized that a complete change of expression had taken place. Differences which seem very pronounced when expressed in the 50 or more plants of a progeny row may easily be overlooked in a single individual.

[2] The crop of 1913 amounted to about 2,100 bales, and about 15,000 acres were planted in 1914.

THE YUMA VARIETY

As compared with the parent Mit Afifi, the Yuma variety is readily distinguished by its more frequently 5-lobed leaves (Pl. XIX); larger involucral bracts (Pl. XXII, fig. 2), which tend to be oblong-ovate rather than triangular-ovate and are usually united near the base so as to form a closed cup around the base of the boll; much longer and more tapering bolls (Pl. XXIV, fig. 2); and longer, lighter colored fiber. The fiber averages about 1½ inches long and resembles in color that of the Egyptian Yannovitch. In the characters of the foliage, involucres, and bolls the Yuma variety shows a striking resemblance to the Egyptian Nubari (Pl. XXII, fig. 1, and Pl. XXIV, fig. 1) which had appeared in Egypt three or four years earlier, presumably also by mutation from the Mit Afifi.[1] The fiber of the two varieties is quite different, however, that of the Yuma being longer and lighter colored.

The Yuma variety showed from the beginning a high degree of uniformity. In 1909 a 4-acre field was grown near Yuma, Ariz., having been planted with seed from those plants in the progeny row of 1908 which were not individually selected. Every plant in this field was examined in June, when 2 per cent of the total number were removed because they showed signs of hybrid origin or were otherwise undesirable. A second census in July resulted in the removal of an additional 0.5 per cent of the plants. The fact that not more than 2.5 per cent of the plants in this field showed a noteworthy departure from the type indicates a strong predominance of self-pollination or else a high degree of prepotency, since the progeny row of 1908 was situated between two rows of plants of wholly different character and since in 1906 and 1907 the stock from which this mutant came had been exposed to cross-pollination by Upland varieties of cotton.[2]

In 1913 Messrs. G. B. Gilbert and M. W. Buster, of the Office of Acclimatization and Adaptation of Crop Plants and Cotton Breeding, Bureau of Plant Industry, examined all the plants in two fields of the Yuma variety at Mesa, Ariz. Although these fields aggregated about 50 acres in extent and contained several hundred thousand plants, only about one dozen individuals were discovered which gave clear evidence of contamination with Hindi or with Upland cotton.

THE PIMA VARIETY

The Pima variety originated in 1910 with a single plant of marked individuality which was found growing in a field of the Yuma variety. During the three subsequent generations this type has shown a striking

[1] Since the Mit Afifi seed with which the breeding work was begun in Arizona was imported in 1901, two years before the appearance of the parent individual of the Nubari variety; and since the latter is too distinct from Mit Afifi to be overlooked in progeny rows in which every individual plant was closely inspected, the possibility of a direct descent of the Yuma from the Nubari seems definitely excluded.

[2] Careful examination of all the plants in the Egyptian cotton progeny rows in 1908 showed that 8.1 per cent of the total number were Egyptian X Upland hybrids. In the Yuma variety row 7 plants out of 162, or about 4 per cent of the total number of individuals, were hybrids.

degree of uniformity in its very distinct botanical characters. The principal characters by which it differs from the parent Yuma variety are enumerated in Table I, p. 291. The Pima variety bears a marked resemblance to the discarded Somerton variety in the shape of the leaves, involucres, and bolls, but is almost the antithesis of that variety in its branching habit and seed characters. The Somerton showed an extreme development of the vegetative branches (much more so even than the Yuma) and had nearly smooth seeds, while the seeds of the Pima variety are very fuzzy for an Egyptian type.

HISTORY OF THE PIMA COTTON

In 1909 several selections, made in the original progeny row (No. 382) of the Yuma variety, were grown as progeny rows at Sacaton, Ariz., and of these No. 382–10, which was thoroughly typical of the variety, proved to be the best. Several acres were planted in 1910 with bulk seed from this row,[1] and numerous individual selections were made in this field. Of these, plant No. 382–10–0–14 was the progenitor of the Pima variety. This plant attracted particular attention because of its large and very sharp-pointed bolls. An excellent progeny row was grown in 1911 from the seed of this individual, and five individual selections were made in this row. These selections were characterized by the marked reduction of the vegetative branches and by the retention of fruiting branches exceptionally low on the main stem. The selection which produced the best progeny the year following (plant No. 382–10–0–14–5) was noted as having the first fruiting branch low on the main stem (at node 10), the limbs much reduced, and the bracts nearly distinct.

The five progeny rows grown from these selections at Sacaton in 1912, when observed in July, greatly resembled each other and presented a very distinct and uniform type. They were in strong contrast to all other groups of progenies in the breeding nursery by reason of the marked reduction of the vegetative branches, which were generally fewer and were uniformly much shorter than in the Yuma variety. In one of the rows the reduction amounted to practical suppression. Correlated with this there was a strong tendency to retain the fruiting branches at a lower node of the main stem and to retain more bolls on the lower fruiting branches than is usual in the Yuma variety.

Row No. 382–10–0–14–5 proved more uniformly productive and long fibered than the other four, although the development of the vegetative branches was somewhat greater than in one of the other rows.[2] Twenty individual selections were made in this row and a smaller number in three of the other progeny rows of this type. Fourteen of the selections in row

[1] This field was carefully rogued, and the resulting seed was planted for increase in 1911. This was the source of the seed used in commercial plantings in 1912, 1913, and 1914. Hence, the Yuma variety as now grown by farmers in the Salt River Valley is derived from Selection No. 382–10.

[2] The 1913 progenies from selections in row No. 382–10–0–14–5 showed, however, less development of limbs than did the progenies from the other rows.

No. 382–10–0–14–5 were grown in progeny rows in 1913, when the superiority of this group as compared with the related groups of progenies was incontestable.

In July, 1913, careful examination failed to reveal any noteworthy departure from the type of the variety among the approximately 1,000 individuals in the progeny rows of this group. Hence, in the third generation from the parent individual this type showed practical uniformity in the expression of its botanical characters.

CHARACTERS OF THE PIMA COTTON

Main stem stout, its internodes rather long, its first fruiting branch usually borne at the ninth or tenth node; vegetative branches few, remaining much shorter than the main stem and developing late or, frequently, altogether wanting; fruiting branches long, becoming pendulous, having a very long first internode; leaves large and thick, those of the main stem usually deeply 5-lobed, involucral bracts triangular ovate, separate or nearly so to the base; bolls large, plump, conical, very sharply and rather abruptly pointed, light green in color and not deeply pitted; seeds large, having both ends and often a part of their faces covered with bright green fuzz; fiber long (1⅝ to 1¾ inches), in color very pale buff with a tinge of pink.

THE GILA VARIETY

The Gila variety originated with a plant discovered in 1908 by Mr. E. W. Hudson[1] in a field planted with the same stock of acclimatized Mit Afifi cotton which gave rise to the Yuma and the Somerton varieties. The distinctness of the characters of the parent individual and the uniformity with which these characters have been expressed in its descendants justify the conclusion that this variety, also, is of mutational origin. The Gila variety is very distinct from the Yuma variety. It resembles the Mit Afifi as grown in Arizona from imported seed, in the characters of the leaves, involucres, and bolls, but differs in its smaller vegetative branches, better fruiting branches, earlier ripening, much greater productiveness, and much longer and lighter colored fiber. Two selections made by Mr. Hudson in 1910, one having larger bolls and the other longer fiber than the parent variety, probably represent mutations from the Gila.

HISTORY OF THE GILA COTTON

In regard to the parent individual, Mr. Hudson states that it had much browner fiber and ripened considerably earlier than the surrounding plants. In appearance the original plant was rather dwarf and the leaves very deeply lobed, much more so than in the average plants in the field, which gave a strikingly open appearance to the plant.

[1] An account of this variety is here presented with the concurrence of Mr. Walter T. Swingle, Physiologist in Charge of the Office of Crop Physiology and Breeding Investigations, Bureau of Plant Industry. This office administers the Cooperative Testing and Demonstration Gardens at Sacaton, Ariz., of which Mr. Hudson is superintendent, in cooperation with the Bureau of Indian Affairs, Department of the Interior.

In 1909 a progeny row of 16 plants was grown at Sacaton from seed of this selection and showed a remarkable degree of uniformity in the plants and the fiber. In 1910 a half-acre plat was planted with the seed from this progeny row. During subsequent years the plantings have been gradually increased until, in 1913, 200 acres were grown on the Pima and the Maricopa Indian Reservations in southern Arizona (Pl. XVII).

CHARACTERS OF THE GILA COTTON

Main stem rather slender, with relatively short internodes, its first fruiting branch usually borne at the ninth or tenth node; vegetative branches slender, developing late, usually remaining shorter than the main stem; fruiting branches with rather short internodes and numerous bolls; leaves rather small, those of the main stem usually 3-lobed, the lobes deep; involucral bracts triangular ovate, separate or nearly so to the base; bolls short, plump, abruptly narrowed to the blunt apex; seeds large, having usually one-third to one-half of the surface covered with fuzz; fiber about $1\frac{7}{16}$ inches long, somewhat darker colored than in the Yuma and Pima varieties.

THE MUTABILITY OF EGYPTIAN COTTON

Four distinct varieties of Egyptian cotton—Yuma, Somerton, Pima, and Gila—have arisen in the course of plant-breeding work in Arizona. Three of these were derived directly from the Mit Afifi, while the Pima variety is an offshoot from the Yuma. Each of these varieties originated with a plant which was very different from the parent stock, and the distinctive characters have continued to be expressed with a high degree of uniformity during several generations. These facts seem to warrant the conclusion that the varieties mentioned are derived from mutants comparable with those of *Oenothera Lamarckiana* as described by De Vries.[1] The abrupt and distinct change of expression of characters in the parent individuals places the phenomenon outside the range of mere fluctuation, while the uniformity with which the new[2] characters have been expressed in each subsequent generation makes it wholly unlikely that these forms are an immediate product of hybridization.

As to the varieties which have originated in Egypt, while their history is much less completely known than that of the Arizona varieties, the data at hand point strongly to the conclusion that they also have been derived from mutants.

[1] The presence each year in the field plantings of the new varieties of Egyptian cotton of a small percentage of "off-type" plants is readily explained by the fact that the individuals which gave rise to the varieties were not protected from cross-pollination by surrounding plants of different character. De Vries (1909, v. 1, p. 275) states that before he resorted to bagging and self-pollinating the flowers of his mutants "these strains exhibited a very high degree of, though not an absolute, constancy."

[2] It is highly improbable that any of the characters exhibited by these mutants are new in the sense of having been absent in all lines of the ancestry. The history of Egyptian cotton indicates that more than one species of Gossypium has contributed to the formation of the type. It is therefore probable that a large share of the characters which are possessed by the different members of this genus have been transmitted in the Egyptian complex and may come to expression in its mutants.

A point of interest in connection with the origin of varieties in this type of cotton is the independent appearance of forms which are nearly identical in several of the characters by which they differ from the parent stock. As was pointed out on a preceding page, the Yuma variety is almost the exact counterpart, in foliage, involucres, and bolls, of the Nubari variety, which appeared in Egypt three years before the Yuma variety appeared in Arizona. Both varieties are derived from the Mit Afifi, which has very different characters. It has also been shown that the Pima variety, a descendant of the Yuma, bears a close resemblance in some of the characters by which it differs from its parent to the Somerton variety, which had appeared simultaneously with the Yuma three years previous to the appearance of the Pima variety. This independent appearance of the same or very similar new characters is paralleled in the case of *Oenothera Lamarckiana*, which has repeatedly given rise to identical or nearly identical mutants.

While mutation in these two plants appears to be essentially the same phenomenon, it is very much more active in *Oenothera Lamarckiana*. In De Vries's cultures during the first seven generations 1.5 per cent of the total number of individuals were mutants. On the other hand, in the Egyptian cotton grown in Arizona one conspicuously mutating individual among many thousand appears to be the limit of expectation. Even the heterogeneous stock of the Mit Afifi variety, which was introduced into Arizona 12 years ago, has produced only three or four mutants of a striking character, and in the more closely selected Yuma variety, which is now 7 years old, only one noteworthy mutant, the Pima, has been detected among the several thousand plants grown in progeny rows in each generation.[1]

The evidence at hand indicates that Egyptian cotton is a mutable group and that the mutability is of a type very similar to that occurring in *Oenothera Lamarckiana*. In seeking an explanation of the occurrence of mutation in Egyptian cotton it is therefore in order to consider certain theories which have been advanced to account for the mutability of Oenothera.

Shortly after the publication of De Vries's work it was suggested by Bateson and Saunders (1902) that the appearance of mutants in *Oenothera Lamarckiana* is due to hybridization. Other biologists have since adopted this idea. Thus, Tower (1910, p. 315-316), discussing the results of his experiments in crossing different species of Leptinotarsa, a genus of beetles in which, beginning with the sixth hybrid generation, the hybrid bred true except for the occasional appearance of mutant-like individuals, states: "These strains . . . gave results which strongly suggested that the interpretation of a mutative period, as described by De Vries in *Oenothera Lamarckiana*, may well be the variability which follows complex processes of hybridization."

[1] It does not follow that numerous minor or undesirable variants, eliminated each year in the process of roguing, might not, if subjected to the test of line breeding, prove to be mutants.

Davis (1911–1913) has sought to demonstrate experimentally that *Oenothera Lamarckiana*, which is not known to occur in the wild state anywhere in North America, originated as a hybrid between *O. biennis* and *O. grandiflora*.

Gates, while holding that *Oenothera Lamarckiana* could not have originated from a simple cross of *O. biennis* with *O. grandiflora*, believes that mutation and hybridization are associated phenomena. He says:

> Mutation in *O. Lamarckiana*, therefore, appears to be a condition of germinal instability and not a simple process of hybrid splitting, although this condition of instability has probably been brought about through previous crossing in the ancestry (Gates, 1911, p. 605; *see also* 1913a, p. 58–59).

On the other hand, Heribert-Nilsson (1912, p. 213) concluded from the results of his extensive hybridization experiments with this plant that the mutants can all be explained as either plus or minus combinations of characters already present in *O. Lamarckiana*. In his opinion instability of the germ plasm does not need to be assumed, and the whole phenomenon of mutation should be interpreted from one standpoint—that of Mendelian recombinations. He further concluded (1912, p. 218) that the mutants are not progressive or regressive new forms originated through the spontaneous appearance or disappearance of a single unit character—that is, through mutation in the sense of De Vries—but are minus combinations—that is, they have originated through the recombination of Mendelian characters already present in the parent species and distributed among different individuals.

In a recent paper, Gates (1913b) rejects these conclusions of Heribert-Nilsson on the ground that they are contrary to the cytological evidence and maintains the position (p. 298) that "mutation is an independent process requiring a special explanation."

The preponderance of evidence points to the conclusion that hybridization, possibly remote and of a complex nature, has been a factor in the mutability of Oenothera. On the other hand, the theory of Mendelian recombination does not afford adequate explanation of all the phenomena observed.

It remains to consider the evidence that hybridization has been a factor in the mutability of Egyptian cotton. The facts that hybrids between distinct types of cotton show great diversity in the F_2 and later generations and that it is difficult to obtain constant varieties by hybridization are well known to cotton breeders.[1] Yet, if the F_2 plants and their progeny during successive generations should be cross-

[1] The Foster variety is one of the few well-authenticated examples of a commercially important variety of known hybrid origin, having originated as the result of a cross between the Sunflower (a small-bolled long-staple Upland variety) and the Triumph (a large-bolled, short-staple Upland variety) made by Dr. D. A. Saunders. Although after several years of selection this variety has attained sufficient stability to warrant commercial production, the Foster variety is apparently much less uniform than the Yuma and other varieties of Egyptian cotton which have presumably originated by mutation. Individuals having the large, broad leaves and the short fiber of the Triumph variety are still frequently met with. (Cook, 1912, p. 17–18; 1913a, p. 16.)

pollinated with the same type which furnished one of the parents of the original hybrid, it is conceivable that finally only the characters of this parent would continue to be expressed. A hybrid of this kind, although very "dilute," might be expected to be in unstable equilibrium and, hence, to offer the proper conditions for the appearance of mutants.[1]

If we accept the hypothesis that mutability is a consequence of hybridization, it is not difficult to account for the tendency of Egyptian cotton to produce mutants. As was pointed out on preceding pages, the type as a whole is believed by some authorities to have originated from crosses between distinct species of Gossypium. But even if this theory be rejected, the possibility that hybridization has been a factor in the mutability of this cotton is not removed, since (1) the different varieties which, although genetically related, are distinct in their characters, are in Egypt often grown in close proximity and their seeds frequently become mixed at the gins, so that a great deal of crossing takes place among them; (2) other types of cotton which readily hybridize with the Egyptian, such as the American Upland and Sea Island, have been repeatedly introduced into Egypt and precautions to keep them isolated have rarely if ever been taken; (3) practically every cotton field in Egypt contains numerous plants of the very distinct Hindi type, which crosses with the Egyptian, producing more or less fertile offspring.[2]

The mixed condition of the principal Egyptian varieties has been strikingly exemplified in the Arizona plantings grown from imported seed. These always contain a greater or less number of Hindi plants and of first generation hybrids between these and the Egyptian, together with a multitude of individuals which give evidence of earlier crossing by their less pronounced expression of Hindi characters. Even the Sakellaridis variety, which is only about eight generations removed from the parent individual, has shown itself to be badly contaminated.

The theory that the mutability of Egyptian cotton is an after effect of hybridization with such distinctly different types as Hindi, Upland, or Sea Island, might be challenged on the ground that the recent mutants show no characters which can definitely be attributed to a non-Egyptian parent. This certainly appears to be the case with the Arizona varieties, which are purely Egyptian in the characters expressed. The objection may be met by assuming that the immediate ancestors of the mutating individuals were "diluted" hybrids, which, while expressing only Egyptian characters, were in a condition of unstable equilibrium, favorable to mutation. This assumption would imply that the remote non-Egyptian ancestor has made no direct contribution to the characters expressed in the mutating descendant and that the only remaining

[1] The possibility of inducing the production of desirable mutants by specially planned hybridization has been suggested by Mr. O. F. Cook (1913b, p. 86-87).

[2] According to Prof. Balls (1907, p. 57), "all varieties of Egyptian cotton, new or old, contain at least 50 per cent of plants with hybrid constitutions." In another work the same author (1912, p. 5) states: "The nominal varieties are more or less heterogeneous complexes of heterozygotes."

influence of hybridization is the disturbance of germinal equilibrium which manifests itself in the production of mutants. Since, furthermore, the distinctive characters of the mutants were not observed, singly or in combination, among nearly related individuals of the parent stock, the "germinal instability" theory of Gates appears preferable to the "Mendelian recombination" hypothesis of Heribert-Nilsson as an explanation of the known facts regarding mutation in Egyptian cotton.

Whatever may be the true explanation of the mutability of Egyptian cotton, there can be no question that the occurrence of mutants of a desirable character, and the relative uniformity during several generations of the resulting varieties, have been a safeguard to the cotton industry of Egypt. As fast as the old varieties have deteriorated through crossing with one another and with Hindi cotton, new varieties have been at hand to replace them.

In the varieties which have developed in Arizona, persistent roguing has so nearly eliminated the Hindi and Upland elements that they are scarcely detectable upon careful examination of thousands of plants (see p. 292). These varieties may therefore be expected to remain uniform much longer than those which are grown in Egypt, provided that they are kept isolated from each other and from other types of cotton. If, notwithstanding, deterioration should ultimately take place, the mutability of the type affords ground for the hope that new varieties of equal or greater value will be forthcoming. The contingency should, however, be borne in mind that these varieties, so long as they are protected from crossing with other forms, are likely to be less productive of mutants than was the heterogeneous stock of the Mit Afifi variety from which they originated.[1] It is significant in this connection that in the Yuma variety during seven generations only one striking and desirable mutant has been detected among thousands of plants and that in the Pima variety, which is derived from the mutant in question, no tendency to further mutation has yet been observed.

SUMMARY

The origin of the Egyptian type of cotton is obscure. According to one theory, it is a product of hybridization between a brown-linted tree cotton and American Sea Island, both of these types having been cultivated in Egypt nearly a century ago. Whether or not this be true, there can be no question that the varieties now grown are of mixed ancestry, a condition which some investigators regard as favorable to mutation.

Numerous varieties have appeared from time to time in Egypt. The Ashmuni variety, now grown only in Upper Egypt, originated about 1850, This variety gave rise in 1887 to the Mit Afifi, and from the latter the

[1] "As a rule the new species proved much less mutable than the original *O. Lamarckiana* from which they originated. It is only the inconstant forms amongst them which exhibit a very high degree of mutability, as, for example, *O. scintillans*." (De Vries, 1909, v. 1, p. 296.)

Abassi, Yannovitch, Nubari, Sakellaridis, and Assil varieties have successively been developed.

As grown in Arizona from imported seed, most of the Egyptian varieties are readily distinguishable by the habit of the plants and by the characters of the leaves, involucres, and bolls, as well as of the fiber.

So far as the scanty evidence goes, each of these varieties originated with a mutant—i. e., an individual plant which showed an abrupt and definite change in the characters expressed. This conclusion is supported by the more complete data at hand regarding the history of the varieties which have been developed in Arizona.

Plant-breeding work in Arizona was begun 12 years ago with imported seed of the Mit Afifi variety. Persistent selection of the best plants caused some improvement in earliness and productiveness and in the quality of the fiber, but the progress was not very substantial prior to 1908, in which year two types very different from the Mit Afifi were recognized and isolated. One of these was the Yuma variety, now commercially grown in Arizona. This form has continued to express its distinctive characters with a high degree of uniformity, notwithstanding the fact that the parent individual and its immediate progeny were not protected against cross-pollination.

Two additional varieties, described in this paper under the names "Pima" and "Gila," have lately been developed in Arizona. The Pima variety appeared as a single plant of marked individuality in a field of Yuma cotton at Sacaton, Ariz., in 1910. Its characters have been expressed in its progeny with great uniformity during the three subsequent generations. This variety is easily distinguished from the parent Yuma variety by its relative limblessness and by the correlated retention of the lowest fruiting branches and bolls; by the more uniformly deeply 5-lobed leaves; by the shorter, relatively wider, and nearly separate involucral bracts; by the plumper and more abruptly and sharply pointed bolls; and by the longer fiber.

The Gila variety is derived from a single plant discovered by Mr. E. W. Hudson in a field of the acclimatized Mit Afifi stock grown at Sacaton, Ariz., in 1908. In its external characters this type resembles the parent Mit Afifi variety much more than the Yuma, but differs from the Mit Afifi in its earlier ripening, smaller vegetative branches, greater productiveness, and longer fiber. The individuality of the parent plant, together with the uniformity shown by its progeny during the subsequent generations, indicates that the Gila variety, like the Yuma and the Pima, is of mutational origin.

Egyptian cotton exhibits, although in a minor degree, the tendency to develop new varieties by mutation which characterizes *Oenothera Lamarckiana*. There is a further parallel in the fact that in both cases very similar, if not identical, new characters come into expression at

different times and in different places. An example of this phenomenon in Egyptian cotton is afforded by the Nubari and the Yuma varieties.

If the tendency to produce mutants is a result of remote or complex hybridization, the mutability of Egyptian cotton might be accounted for upon either of the following grounds: (1) The supposed hybrid origin of the type as a whole, or (2) later crossing with other types of cotton.

Ever since mutation became recognized as a factor in the breeding of Egyptian cotton the following methods have been followed in Arizona: (1) Recognition and isolation of desirable mutants; (2) selection and comparison on the progeny-row basis of those individuals among their progeny which express most fully the desirable characters of the new type; (3) elimination from the seed-increase fields, preferably before blossoming begins, of the aberrant and otherwise undesirable individuals.

LITERATURE CITED

BALLS, W. L.

1907. Studies of Egyptian cotton. *In* Yearbook, Khediv. Agr. Soc. Cairo, 1906, p. 29–111, pl. 2–16.

1912. The Cotton Plant in Egypt ... 202 p., front., 71 fig. London. Bibliography, p. 181–190.

BATESON, WILLIAM, and SAUNDERS, E. R.

1902. Experimental studies in the physiology of heredity. Rpt. Evol. Com. Roy. Soc. [London], 1, 160 p.

COOK, O. F.

1911. Hindi cotton in Egypt. U. S. Dept. Agr. Bur. Plant Indus. Bul. 210, 58 p., 6 pl.

1912. Cotton improvement under weevil conditions. U. S. Dept. Agr. Farmers' Bul. 501, 22 p.

1913a. Durango cotton in the Imperial Valley. *In* U. S. Dept. Agr. Bur. Plant Indus. Circ. 111, p. 11–22, 5 fig.

1913b. Heredity and cotton breeding. U. S. Dept. Agr. Bur. Plant Indus. Bul. 256, 113 p., 19 fig., 6 pl.

DAVIS, B. M.

1911–1913. Genetical studies on Œnothera. II–IV. *In* Amer. Nat., v. 45, no. 532, p. 193–233, 18 fig., 1911; v. 46, no. 547, p. 377–427, 15 fig., 1912; v. 47, no. 561, p. 547–571, fig. 16–17, 1913.

EAST, E. M., and HAYES, H. K.

1914. A genetic analysis of the changes produced by selection in experiments with tobacco. *In* Amer. Nat., v. 48, no. 565, p. 5–48, 9 fig.

FLETCHER, FREDERIC.

1908. The origin of Egyptian cotton. *In* Cairo Sci. Jour., v. 2, p. 381–385, illus.

GATES, R. R.

1911. Mutation in Œnothera. *In* Amer. Nat., v. 45, no. 538, p. 577–606.

1913a. A contribution to a knowledge of the mutating Oenotheras. *In* Trans. Linn. Soc. London, Bot., s. 2, v. 8, pt. 1, p. 1–68, 6 pl. Bibliography, p. 62–64.

1913b. Recent papers on Œnothera mutations. *In* New Phytol., v. 12, no. 8, p. 290–302. Bibliography, p. 299–300.

HERIBERT-NILSSON, N.

1912. Die Variabilität der Oenothera Lamarckiana und das Problem der Mutation. *In* Ztschr. Indukt. Abstam. und Vererb., Bd. 8, Heft ½, p. 89–231, 36 fig., pl. 3–5. Literatur, p. 221–231.

JOHANNSEN, W.

1913. Mutations dans des lignées pures de haricots et discussion au sujet de la mutation en général. *In* IV^e^ Conf. Internat. Génétique, Compt. Rend. et Rap., 1911, p. 160–163.

KEARNEY, T. H.

1910. Breeding new types of Egyptian cotton. U. S. Dept. Agr. Bur. Plant Indus. Bul. 200, 39 p., 4 pl.

KIESSLING, LUDWIG.

1912. Über eine Mutation in einer reinen Linie von Hordeum distichum L. *In* Ztschr. Indukt. Abstam. und Vererb., Bd. 8, Heft ½, p. 48–78.

TOWER, W. L.

1910. The determination of dominance and the modification of behavior in alternative (Mendelian) inheritance, by conditions surrounding or incident upon the germ cells at fertilization. *In* Biol. Bul., v. 18, no. 6, p. 285–352, 4 fig., 8 pl. Bibliography, p. 336–337.

VRIES, HUGO DE.

1901–1903. Die Mutationstheorie ... 2 v., illus. Leipzig.

1909–10. The Mutation Theory ... Translated by J. B. Farmer and A. D. Darbishire. 2 v., illus. Chicago.

WATT, GEORGE.

1907. The Wild and Cultivated Cotton Plants of the World ... 406 p., illus. London, New York.

PLATE XVII

Field of Egyptian cotton (Gila variety) in blossom at the Cooperative Testing and Demonstration Gardens, Sacaton, Ariz., on July 15, 1913.

PLATE XVIII

Fig. 1.—A plant of the Yuma variety of Egyptian cotton, photographed on July 15, 1913, showing the well-developed vegetative branches and the rather poorly developed lower fruiting branches.

Fig. 2.—A plant of the Pima variety of Egyptian cotton, photographed on July 15, 1913, showing the absence of vegetative branches and the presence of well-developed fruiting branches at the low nodes on the axis.

Fig. 3.—A plant of the Gila variety of Egyptian cotton, photographed on July 15, 1913, showing in comparison with the Yuma variety (Pl. XVIII, fig. 1) a smaller development of the vegetative branches.

PLATE XIX

Leaves of the Yuma variety of Egyptian cotton taken from the main stem and showing the strong tendency in this variety to produce 5-lobed leaves. (One-fourth natural size.)

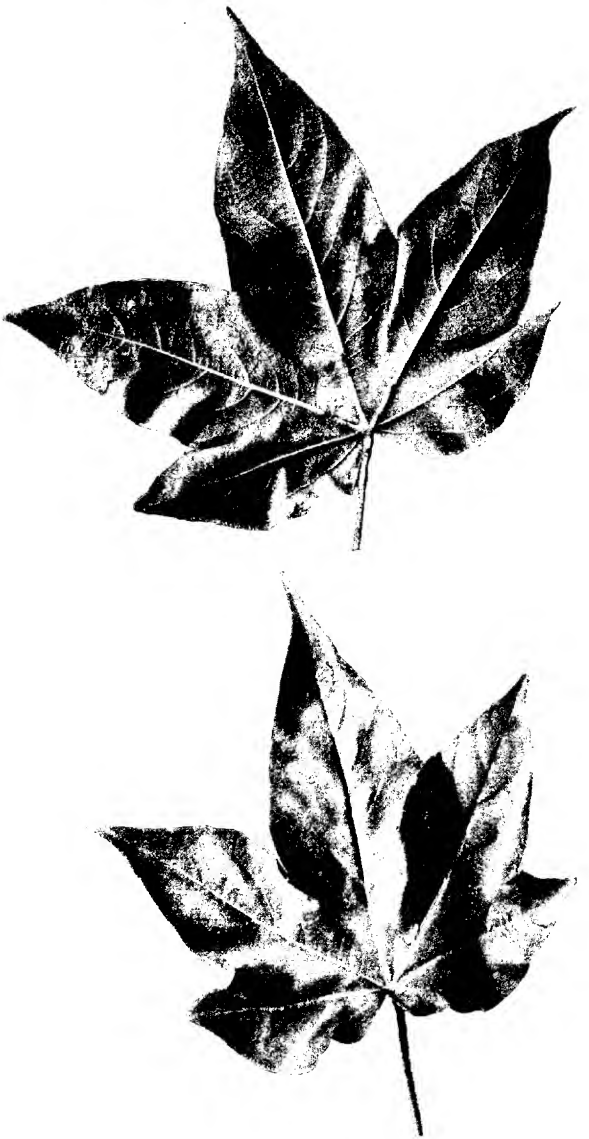
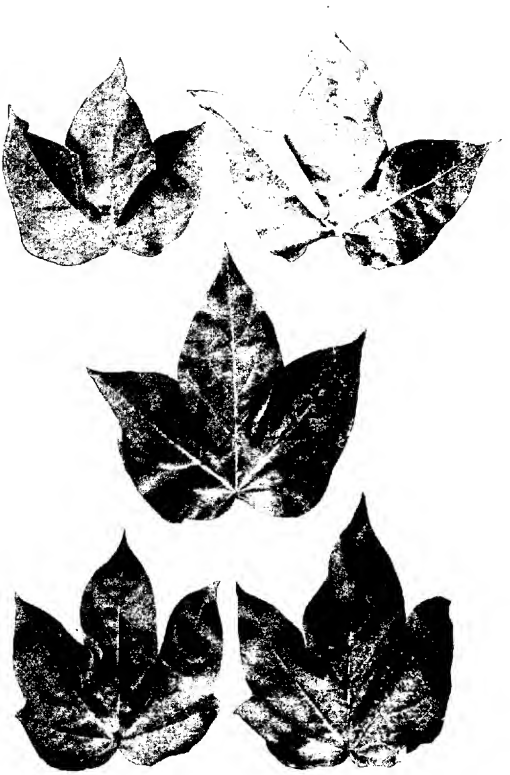


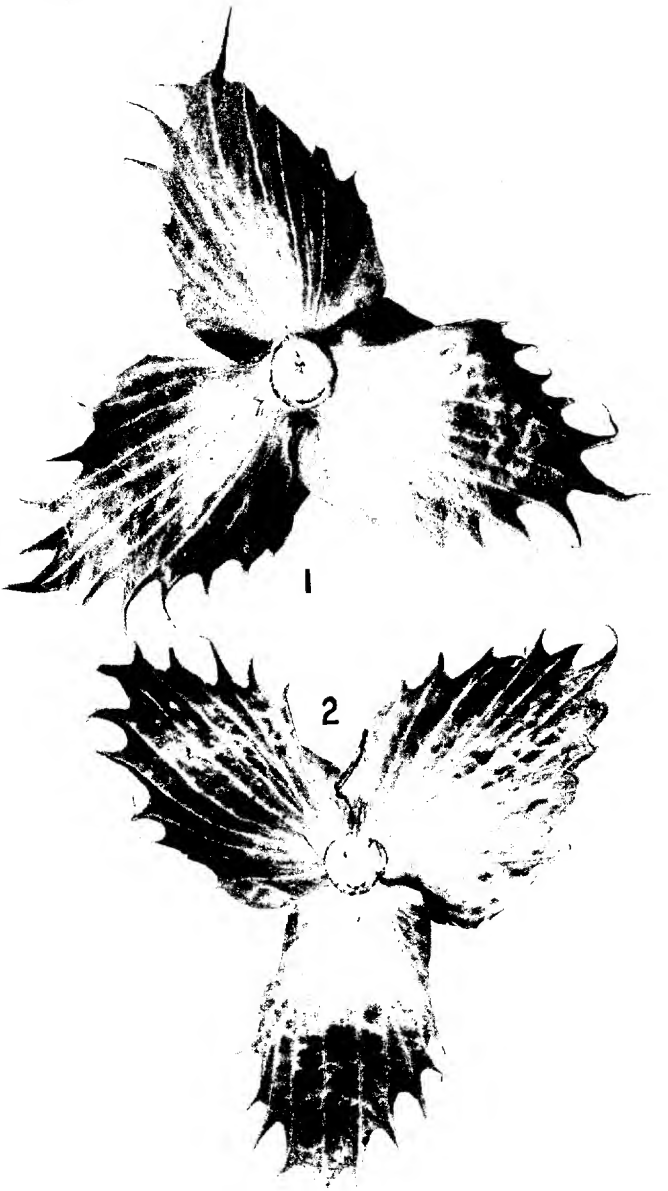
PLATE XX

Leaves of the Pima variety of Egyptian cotton taken from the main stem. In this variety the leaves of the main stem are almost uniformly 5-lobed. (About one-third natural size.)

PLATE XXI

Leaves of the Cila variety of Egyptian cotton taken from the main stem. In this variety the leaves are prevailingly 3-lobed, as is also the case in the Mit Afifi variety. (One-fourth natural size.)

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2

PLATE XXII

Involucres of Egyptian cotton (natural size).

Fig. 1.—Nubari variety.

Fig. 2.—Yuma variety.

In these two varieties the bracts are strongly connate, often forming a closed cup around the base of the boll.

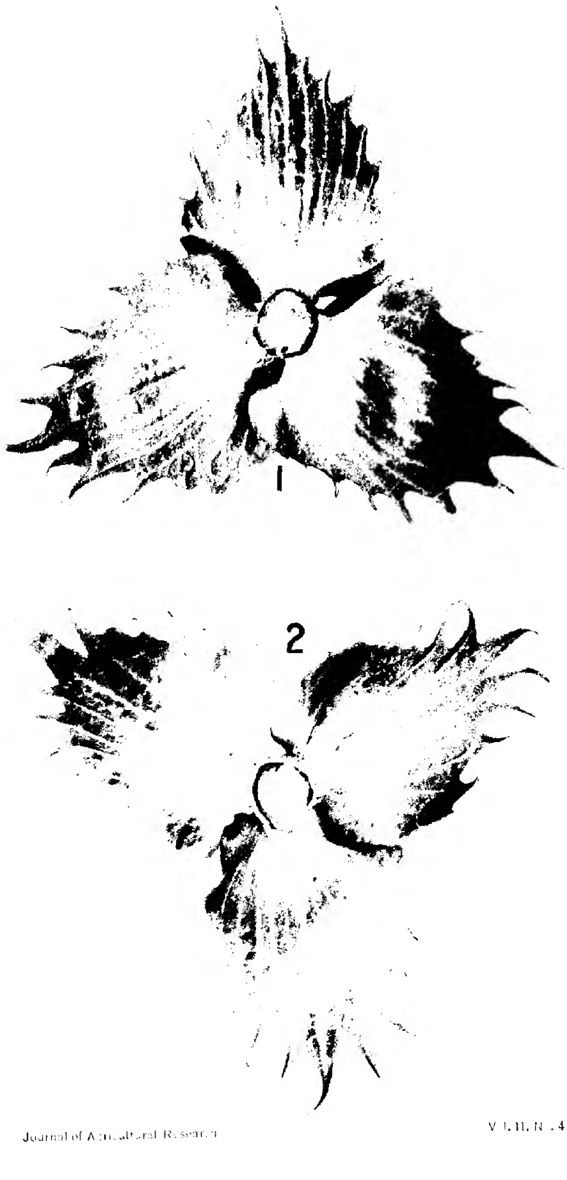
PLATE XXIII

Involucres of Egyptian cotton (natural size).

Fig. 1.—Pima variety.

Fig. 2.—Gila variety.

In these two varieties the bracts are shorter than in the Nubari and the Yuma varieties, and are separate, or nearly so, to the base. The Gila variety closely resembles the Mit Afifi variety in the character of the involucres.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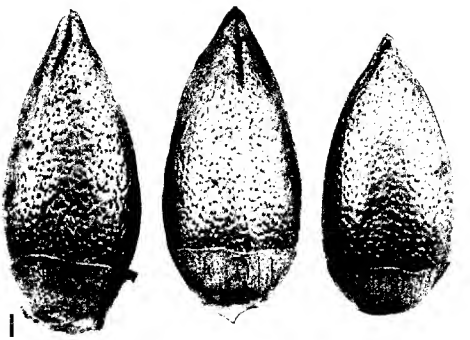
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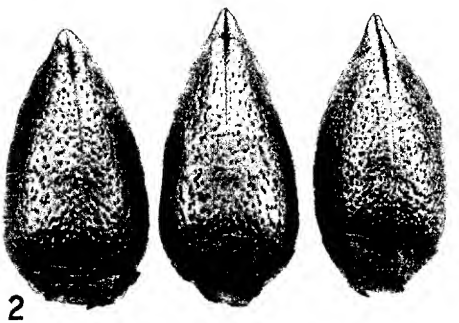
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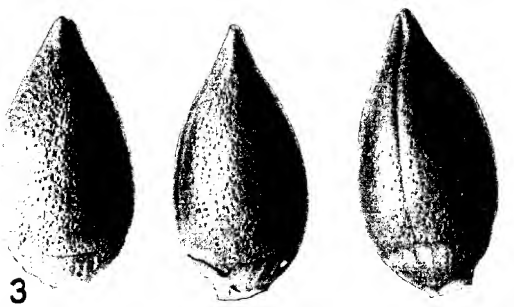
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PLATE XXIV

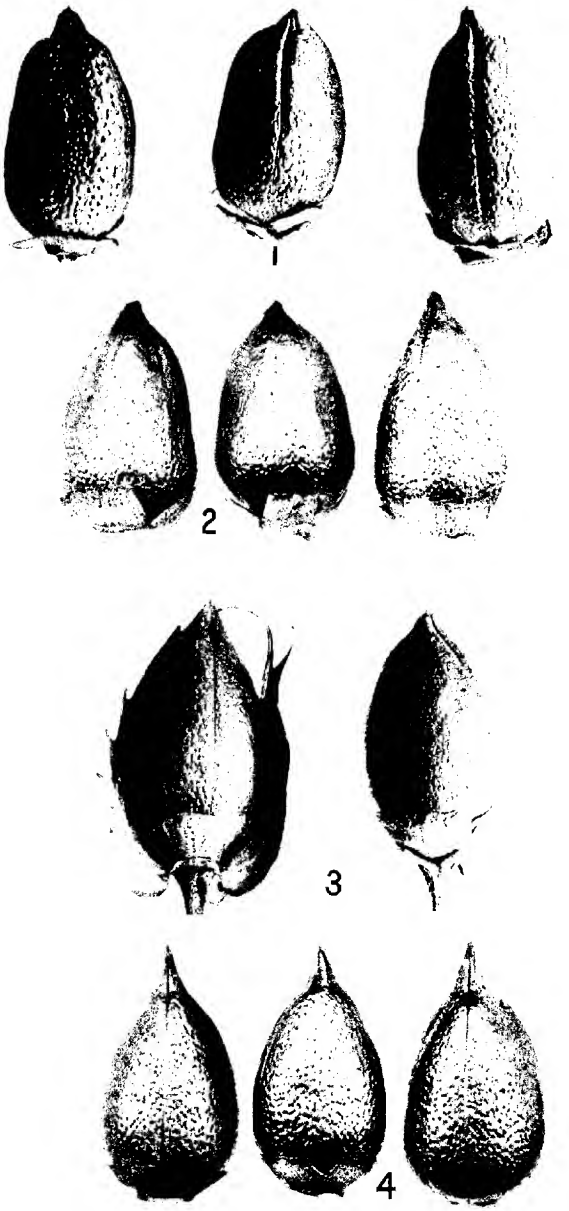
Bolls of Egyptian cotton (natural size).

Fig. 1.—Nubari variety.
Fig. 2.—Yuma variety.
Fig. 3.—Pima variety.
Note the close resemblance in the bolls of the Nubari and the Yuma varieties, and the different shape and shallower pitting of the bolls of the Pima variety.

PLATE XXV

Bolls of Egyptian cotton (natural size).

Fig. 1.—Mit Afifi variety.
Fig. 2.—Gila variety.
Fig. 3.—Big-bolled strain of the Gila variety.
Fig. 4.—Sakellaridis variety.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INFLUENCE OF THE HOST ON THE MORPHOLOGICAL CHARACTERS OF PUCCINIA ELLISIANA AND PUCCINIA ANDROPOGONIS

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Both *Puccinia ellisiana* Thuem. and *Puccinia andropogonis* Schw. have their telial stage on various species of Andropogon. For its æcial stage *Puccinia ellisiana* goes to certain species of Viola, while a number of species of Pentstemon are the æcial host for *Puccinia andropogonis*.

Two years ago the author[1] called attention to the fact that *Puccinia ellisiana* might have its æcial stage on Pentstemon as well as on certain species of Viola.

Culture data obtained in 1913 proved that this supposition was correct, as both Viola and Pentstemon were infected with *Puccinia ellisiana*. The changes produced in the morphological characters of the urediniospores when this rust was carried over to Pentstemon were so radical that the writer would not publish these culture data until they had been tested by another year's work. During the season of 1914, therefore, special attention was given to the infection of species of Viola and Pentstemon with *Puccinia ellisiana* and the infection of Pentstemon and Viola with *Puccinia andropogonis*. The culture work of 1914 agreed absolutely with the results obtained in 1913.

The remarkable feature of the results obtained was not the infection of two widely separated hosts by the same rust, but the changes produced in the morphology of the urediniospores of *Puccinia ellisiana* after passing through Pentstemon as the æcial host. The urediniospores of *Puccinia ellisiana* have thick verrucose walls, while those of *Puccinia andropogonis* have thin, echinulate walls. It is mainly on these well-marked and constant differences in the urediniospores that the two species are distinguished from each other. When urediniospores are not present in the teliosporic material the two rusts are often separated by determining by cultures which is the æcial host, Viola or Pentstemon, of the specimen in hand.

CULTURE DATA FOR 1913

DISSEMINATION OF PUCCINIA ELLISIANA AND PUCCINIA ANDROPOGONIS

The æciospores and urediniospores of both *Puccinia andropogonis* and *Puccinia ellisiana* are not carried far by wind currents. Six feet is the extreme distance yet observed by the writer for the spread of viable spores of either species to near-by stools of Andropogon.

[1] Long, W. H. Notes on three species of rusts on Andropogon. Phytopathology, v. 2, p. 164–171, August, 1912.

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One patch of grass infected by *Puccinia andropogonis* has been observed by the writer for four years, and during this time the size of the infected area has not increased, though there are many stools of Andropogon near the infected area. In the center of this area are several infected groups of plants of *Pentstemon laevigatus*, while at a distance of 40 feet from these there are other plants of the same species. Yet during the last four years the rust has not crossed this 40-foot gap. Eight feet from the infected Pentstemon plants no signs of any rust on the grass can be found, even in the fall of the year after the rust has had all summer to spread. If the rust had ever crossed over the 40-foot gap to the grass near the uninfected Pentstemons, it certainly would have perpetuated itself, since both æcial and telial hosts were present and adjacent to each other. The rust had ample opportunity, as far as contiguity of telial host and proximity of infected plants is concerned, to be carried this distance. Nevertheless, it was limited to the stools of grass immediately adjacent to the infected æcial host, the Pentstemon.

Likewise the æciospores and urediniospores of *Puccinia ellisiana* are not carried over any great distance by the wind and can only infect stools of Andropogon which stand within about 6 feet of the æcial host. This has been previously noted by the writer.[1]

The difficulty with which the urediniospores of either *Puccinia andropogonis* or *Puccinia ellisiana* infect other stools of Andropogon was clearly shown when the writer attempted to obtain a large amount of teliosporic culture material by setting uninfected pots of Andropogon in actual contact with the pots containing the grass already infected from the æciospores. The experiment was a failure, as no infection occurred. The uninfected stools of grass remained free of the rust, even when the tips of the blades intermingled with the blades of the infected stool. Check stools situated 10 to 20 feet from the infected stools and planted in the same cold frame showed no infection.

For two years the writer has attempted to transfer the rust from stool to stool by inoculating with the urediniospores under bell jars in the greenhouse, but has been unsuccessful, even under such favorable conditions. This failure to infect with the urediniospores in the greenhouse may have been due to the high temperature and the condition of the blades of grass. It is probable that in nature these rusts are able to infect adjacent stools of grass on whose leaves the urediniospores fall, but to date the writer has been able to obtain infections on Andropogon only by means of the æciospores. These facts are given in detail to show the improbability of either of these two rusts being mixed in any of the culture material used for the experiments performed in 1913 and 1914.

For five years the writer has been studying in field and laboratory this group of Andropogon rusts, and during that time the peculiarities of

[1] Long, W. H. Op. cit., p. 170.

each have been noted. It is, therefore, with much confidence that the writer sets forth the facts as to the limited spread of each of these rusts in the uredinial stage.

The same thing is true to even a greater extent with *Uromyces andropogonis*. Only one time has the writer been able even to carry this rust from its æcial stage back to the Andropogon, and then only one or two sori were produced.

A careful study of the fresh urediniospores of both *Puccinia ellisiana* and *Puccinia andropogonis* under the microscope seems to indicate that the epispore in both species is either slightly viscid or slightly gelatinous; and, if this be true, it would explain the inability of the urediniospores to spread the rust to distant stools of Andropogon. However, the writer is not at all certain that the epispore when fresh has this viscid character, but the fact is fully established that in this region neither rust will spread very far from its æcial host. In fact, the writer has yet to see a stool of infected grass which had certainly been originally infected by urediniospores. In every instance the infected stools found even in the fall of the year were sufficiently close to the æcial host for the æciospores to have been the only and sole infecting agents. In this respect these rusts differ markedly from the common grain rusts, *Puccinia rubigo-vera* and *Puccinia graminis*, which are able to spread over large areas from the urediniospores alone.

CHARACTER AND SOURCE OF CULTURE MATERIAL

In the culture work of 1913 the teliosporic material used was not pedigreed material from inoculations made under control conditions in the greenhouse, but was material grown for three years under the writer's direct supervision on a plat of ground near his residence in Clarendon, Va. The æcial host each year was *Viola sagittata*, and the telial host was *Andropogon virginicus*. That there are no Pentstemon plants within a radius of a mile of this place was determined by a careful search each year for the last five seasons. The plat of ground used was a glade surrounded on all sides by woods consisting of oaks (*Quercus* spp.) and pines (*Pinus* spp.).

The culture work of 1913 seemed to indicate that the species of the æcial host might influence to some extent the ability of *Puccinia ellisiana* to infect Pentstemon. For instance, teliosporic material whose æcial host was known to be *Viola sagittata* infected Pentstemon, while teliosporic material with *V. papilionacea* as its æcial ancestral host did not. In 1914, however, telial material from either æcial host readily infected the Pentstemon plants. The failure in 1913 of the teliosporic material which had *V. papilionacea* as its æcial ancestral host to infect Pentstemon was probably due to two things:

(1) The first series of inoculations with the rusts from this æcial host was made too early. The Pentstemon plants used had not yet reached their susceptible period.

(2) The second series of tests came so late in the season that it was either too hot in the greenhouse to infect the Pentstemon or the telial material had lost its ability to infect this unusual host under the existing conditions.

The writer used two species of Pentstemon in the culture experiments for 1913 and 1914, *Pentstemon laevigatus* from Virginia and *Pentstemon tubiflorus* from Texas. Only the former was infected by either *Puccinia andropogonis* or *Puccinia ellisiana*. When the leaves of *Pentstemon laevigatus* are first formed, they are covered with many small deciduous hairs, which fall off as the leaf gets older and leave the upper surface of the leaf nearly smooth. The leaves are usually not susceptible to either rust until after these hairs have disappeared. When the leaves get very old they lose their susceptibility entirely.

There is also often found intermixed with the usual form a strain of *Pentstemon laevigatus*, which retains its hairiness and is at all times immune to the rust.

During the spring of 1913 the writer continued the experiments reported for 1912[1] with *Puccinia ellisiana* and *Uromyces andropogonis* Tracy and also carried on culture experiments with *Puccinia andropogonis* and a Puccinia from Oklahoma on *Andropogon furcatus*, whose æcial host proved to be *Oxalis stricta*. Only the results obtained from *Puccinia ellisiana* and *Puccinia andropogonis* are given and discussed here.

To show clearly the pedigree of each lot of teliosporic culture material used in the experiments, the æcial ancestral host for each year is given in the second column of Tables I–IV under the heading "Æcial ancestral host."

The teliosporic material used in all the experiments here recorded was on *Andropogon virginicus*, and the inoculations were made under control conditions in the greenhouses of the Department of Agriculture at Washington, D. C.

TABLE I.—*Teliosporic culture data for Puccinia ellisiana and P. andropogonis*

PUCCINIA ELLISIANA

Species inoculated.	Æcial ancestral host.	Date of inoculation.	Degree of infection.	Pycnia.	Æcia.
		1913.		1913.	1913.
Viola tricolor (cultivated pansy).	Viola sagittata	Apr. 7	Very vigorous	Apr. 15	Apr. 21
Viola sororia	Viola papilionacea	Mar. 20	Good	Apr. 1	Apr. 14
Do	do	Mar. 24	do	Apr. 7	Do.
Do	do	Apr. 15	Fair	Apr. 22	Apr. 30
Do	do	Mar. 20	Only one sorus	Mar. 28	Apr. 2
Viola sagittata	do	Mar. 24	Good	Apr. 2	Apr. 14
Do	do	Mar. 28	do	Apr. 7	Apr. 16
Viola hirsutula	do	do	Fair	do	Apr. 15
Viola pedata	do	Mar. 20	No infection		
Do	do	Mar. 24	do		
Do	do	Mar. 28	do		

[1] Long, W. H. Op. cit., p. 164.

TABLE I.—*Teliosporic culture data for Puccinia ellisiana and P. andropogonis*—Contd.

PUCCINIA ELLISIANA—continued

Species inoculated.	Æcial ancestral host.	Date of inoculation.	Degree of infection.	Pycnia.	Æcia.
		1913.		1913.	1913.
Viola canadensis	Viola sagittata	May 13	No infection[1]		
Viola emarginata	Viola papilionacea	Mar. 20	Poor	Apr. 1	Apr. 8
Do	do	Mar. 24	Fair	Apr. 3	Apr. 13
Viola palmata	Viola fimbriatula	May 8	Very vigorous	May 20	May 27
Viola triloba	Viola papilionacea	Mar. 28	do	Apr. 8	Apr. 15
Do	do	May 8	No infection		
Do	Viola sagittata	Apr. 15	Good	Apr. 28	May 1
Do	do	May 7	do	May 18	May 20
Viola primulifolia	Viola papilionacea	Mar. 20	No infection[2]		
Do	do	Mar. 24	do		
Do	do	Mar. 28	do		
Do	Viola sagittata	Apr. 2	do		
Oxalis stricta	Viola papilionacea	Mar. 20	do		
Do	do	Mar. 24	do		
Do	do	Mar. 28	do		
Do	Viola sagittata	Apr. 2	do		
Do	do	Apr. 8	do		
Pentstemon laevigatus	Viola papilionacea	Mar. 20	do		
Do	do	Mar. 28	do		
Do	do	Apr. 15	do		
Do	do	May 5	do		
Do	Viola sagittata	Apr. 2	Very vigorous	Apr. 8	Apr. 20
Do	do	Apr. 6	do	Apr. 12	Apr. 21
Do	do	Apr. 7	do	Apr. 15	Apr. 24
Do	do	May 7	No infection[2]		
Do	do	May 8	do		
Do	Viola fimbriatula	do	do		
Do	do	do	do		

PUCCINIA ANDROPOGONIS

Pentstemon laevigatus	Pentstemon laevigatus	Mar. 20	No infection[3]		
Do	do	Mar. 26	Vigorous	Apr. 2	Apr. 12
Do	do	Mar. 28	do	Apr. 4	Apr. 14
Do	do	Apr. 2	No infection		
Do	do	Apr. 15	do	Apr. 22	May 1
Viola sagittata	do	Mar. 20	No infection		
Do	do	Mar. 26	do		
Do	do	Mar. 28	do		
Do	do	May 5	do		
Viola triloba	do	Apr. 28	do		
Do	do	May 15	do		
Viola papilionacea	do	Mar. 20	do		
Do	do	Mar. 24	do		
Do	do	Mar. 26	do		
Do	do	Mar. 28	do		
Do	do	Apr. 4	do		
Viola pedata	do	Mar. 20	do		
Do	do	Mar. 24	do		
Do	do	Mar. 28	do		
Do	do	Apr. 2	do		
Viola sororia	do	Mar. 20	do		
Do	do	Apr. 2	do		
Viola emarginata	do	Mar. 20	do		
Do	do	Mar. 24	do		
Do	do	Apr. 7	do		
Viola primulifolia	do	Mar. 24	do		
Do	do	Mar. 28	do		
Oxalis stricta	do	Mar. 20	do		
Do	do	Mar. 24	do		
Do	do	Mar. 28	do		

[1] Plant too old and weather too hot. [2] Weather too hot. [3] Plants not yet susceptible.

CULTURE DATA FOR ÆCIAL INOCULATIONS MADE IN 1913 ON GRAMINACEOUS HOSTS

All the inoculations here recorded were made with pedigreed material grown under control conditions in the greenhouses of the Department of Agriculture at Washington, D. C.

TABLE II.—*Æcial inoculations with Puccinia ellisiana and P. andropogonis*

PUCCINIA ELLISIANA

Species inoculated.	Æcial ancestral host.	Date of inoculation.	Degree of infection.	Uredinia.
		1913.		1913.
Andropogon virginicus	Viola papilionacea, 1912. Viola sagittata, 1913	May 5	Vigorous	May 22
Do	Viola sagittata, 1912. Viola sagittata, 1913	May 7	No infection. Grass was diseased with a systemic smut.	.....
Do	Viola sagittata, 1912. Pentstemon laevigatus, 1913	May 2	Vigorous	May 19
Do	Viola sagittata, 1912. Pentstemon laevigatus, 1913	May 5	.....do	May 22
Zea mays (corn)	Viola papilionacea, 1912. Viola papilionacea, 1913	Apr. 21	No infection, but distinct pallid spots developed.	.....
Do	Viola papilionacea, 1912. Viola triloba, 1913	Apr. 28	No infection	.....
Do	Viola sagittata, 1912. Viola tricolor, 1913 (cultivated pansy).	.....do	.....do	.....
Do	Viola sagittata, 1912. Viola sagittata, 1913	May 5	No infection, but permanent yellow spots developed where germ tubes entered.	.....
Sorghum halepense (Johnson grass).	Viola sagittata, 1912. Pentstemon laevigatus, 1913	Apr. 29	No infection	.....

PUCCINIA ANDROPOGONIS

Andropogon virginicus	Pentstemon laevigatus	Apr. 19	Vigorous	May 2
	.....do	May 5	.....do	May 17
Zea mays (corn)	.....do	Apr. 15	No sori appeared, but yellow spots appeared on blades where inoculated.	.....
	.....do	Apr. 19		
	.....do	May 6		
	.....do	May 15		
Kafir corn	.....do	May 5	No infection, but reddish spots appeared where blades were inoculated.	.....
	.....do	May 7		
Amber-seeded sorghum	.....do	May 5	No infection	.....
	.....do	May 7		
Milo maize	.....do	May 5	.....do	.....
	.....do	May 7	.....do	.....
Sorghum halepense	.....do	May 5	.....do	.....

CULTURE DATA FOR 1914

CHARACTER AND SOURCE OF CULTURE MATERIAL

For the culture work performed in 1914 teliosporic material of *Puccinia ellisiana* was used from six different sources and material of *Puccinia andropogonis* from two different sources.

The teliosporic material of *Puccinia ellisiana* was (1) pedigreed material inoculated under control conditions in the greenhouses of the Bureau of Plant Industry at Washington, D. C.; (2) pedigreed material inoculated under control conditions at Clarendon, Va.; (3) pedigreed material from special selected areas near Courtlands, Va.; (4) pedigreed material from near Vinson, Va.; (5) material from a region free from Pentstemon at Spruce, Va.; and (6) pedigreed material obtained in 1913 by inoculating Pentstemon with the teliospores of *Puccinia ellisiana* under control conditions in the greenhouses of the Bureau of Plant Industry at Washington, D. C., and then using these æciospores to infect Andro-

pogon plants. In this paper this pedigreed teliosporic material (No. 6) is designated "*Puccinia ellisiana* from Pentstemon," in order to distinguish it from the teliosporic material of the ordinary *Puccinia andropogonis*. The source of each individual lot of inoculating material used in 1914 is noted in each table in column 3.

All of the inoculations were made in the greenhouses of the Bureau of Plant Industry at Washington, D. C., and all of the hosts were kept in the greenhouses until the urediniospores were fully developed. The stools of infected Andropogon were then transferred to widely separated cold frames between the different greenhouses where the urediniospores and teliospores could develop normally and yet be entirely free from chance contamination.

If the infected grass is kept in the greenhouse all summer and fall, the rust fails to spread and finally dies, so that no telial material whatever is obtained. This disappearance of the rust from the infected leaves is due to several causes, the most important of which are slugs, high temperature, dry air, and lack of dew at night when under glass in the greenhouse.

TABLE III.—*Teliosporic culture data for Puccinia ellisiana, P. ellisiana from Pentstemon, and P. andropogonis*

PUCCINIA ELLISIANA

Species inoculated.	Æcial ancestral host.	Source of inoculation material.	Date of inoculation.	Degree of infection.	Pycnia.	Æcia.
			1914.		1914.	1914.
Viola tricolor (cultivated pansy).	Viola sagittata.	Pedigreed, Vinson.	Apr. 17	Vigorous	Apr. 28	May 6
Viola tricolor	do	do	May 12	Poor	May 26	June 4
Viola papilionacea	do	do	Apr. 17	Fair	Apr. 29	May 6
Viola palmata	do	do	May 12	do	May 20	June 4
Pentstemon laevigatus.	do	do	Apr. 17	No infection [1]		
Do	do	do	May 12	Fair	May 25	June 2
Do	do	Spruce	Apr. 19	Good	May 10	May 20
Viola tricolor (cultivated pansy).	do	Pedigreed, Clarendon.	Apr. 17	do	Apr. 30	May 7
Do	do	do	Apr. 29	do	Apr. 29	May 15
Do	do	do	Apr. 23	do	May 1	May 12
Viola sagittata	do	do	Apr. 17	Fair	Apr. 29	May 7
Viola papilionacea	do	do	Apr. 16	No infection		
Viola canadensis	do	do	May 11	do		
Pentstemon laevigatus.	do	do	Apr. 16	Vigorous	Apr. 27	May 7
Do	do	do	Apr. 17	No infection		
Do	do	do	Apr. 20	Fair	May 3	May 16
Do	do	do	Apr. 23	do	May 7	May 23
Do	do	do	May 11	No infection		
Do	do	do	May 16	do		
Pentstemon tubiflorus.	do	do	Apr. 10	do		
Do	do	do	Apr. 23	do		
Viola papilionacea	Viola papilionacea.	Pedigreed, Courtlands.	Apr. 17	Fair	Apr. 29	May 10
Do	do	do	Apr. 28	No infection		
Viola tricolor	do	do	Apr. 17	Poor	May 1	May 10
Viola canadensis	do	do	May 8	No infection		
Pentstemon laevigatus.	do	do	Apr. 17	do		
Do	do	do	Apr. 28	Good	May 10	May 20
Do	do	do	May 5	No infection		
Do	do	do	May 8	Good	May 17	May 26

[1] Pentstemon too young.

TABLE III.—*Teliosporic culture data for Puccinia ellisiana, P. ellisiana from Pentstemon, and P. andropogonis*—Continued

PUCCINIA ELLISIANA—continued

Species inoculated.	Æcial ancestral host.	Source of inoculation material.	Date of inoculation.	Degree of infection.	Pycnia.	Æcia.
			1914.		1914.	1914.
Viola tricolor	Viola sagittata	Pedigreed, greenhouse.	Apr. 16	No infection		
Do	do	do	Apr. 20	Good	Apr. 29	May 5
Do	do	do	May 1	Fair	May 11	May 22
Viola tricolor arvensis.	do	do	Apr. 23	do	May 8	May 16
Viola sororia	do	do	Apr. 16	do	Apr. 28	May 10
Pentstemon tubiflorus.	do	do	do	No infection		
Pentstemon laevigatus.	do	do	do	do		
Do	do	do	Apr. 19	Very vigorous	May 10	May 20
Do	do	do	Apr. 20	Vigorous	May 1	May 15
Do	do	do	Apr. 21	do	May 5	May 12
Do	do	do	Apr. 20	do	May 2	May 18
Do	do	do	Apr. 23	do	May 5	Do.
Do	do	do	do	do	May 2	May 15
Do	do	do	Apr. 28	do	May 9	May 20
Do	do	do	do	do	May 14	May 21
Do	do	do	do	do	May 8	May 18
Do	do	do	do	do	May 11	May 20
Do	do	do	Apr. 30	do	May 15	May 25
Do	do	do	May 1	do	May 9	May 22
Do	do	do	do	do	May 10	Do.
Do	do	do	do	do	May 8	May 21
Do	do	do	do	do	May 10	May 20
Do	do	do	do	do	May 11	May 22
Do	do	do	do	do	May 9	May 20
Do	do	do	May 2	do	May 14	May 22

PUCCINIA ELLISIANA FROM PENTSTEMON[1]

Pentstemon laevigatus.	Viola sagittata, 1912. Pentstemon laevigatus, 1913.	Pedigreed, greenhouse.	Apr. 20	Good	May 5	May 20
Do	do	do	May 1	do	May 8	May 22
Do	do	do	May 8	No infection		
Viola tricolor (cultivated pansy).	do	do	Apr. 16	do		
Do	do	do	Apr. 20	Very sparse	May 1	May 8
Do	do	do	Apr. 23	do	May 5	May 14
Do	do	do	Apr. 28	Vigorous	May 8	May 20
Do	do	do	May 1	Sparse	May 14	May 30
Do	do	do	May 8	do	May 20	May 28
Do	do	do	do	do	May 23	June 4
Do	do	do	do	do	May 18	June 2
Viola palmata	do	do	do	Vigorous	do	June 1
Viola sagittata	do	do	Apr. 20	No infection		
Viola papilionacea	do	do	Apr. 16	do		
Do	do	do	Apr. 23	do		
Do	do	do	May 1	do		

PUCCINIA ANDROPOGONIS[2]

Pentstemon laevigatus.	Pentstemon laevigatus.	Queen	May 1	Very vigorous	May 9	May 22
Do	do	do	May 8	Fair	May 19	May 25
Do	do	do	do	No infection		
Do	do	do	do	Fair	May 20	May 27
Do	do	do	do	do	May 19	May 26
Do	do	do	May 16	Very vigorous	May 29	June 3
Do	do	do	May 18	Fair	May 27	June 4

[1] All of the teliosporic material used in this set of experiments was obtained by inoculating *Pentstemon laevigatus* with the teliospores of *Puccinia ellisiana* in the spring of 1913. The resulting æciospores from the Pentstemon leaves were then sown on *Andropogon virginicus*. All was done under control conditions in the greenhouse. The rust thus obtained on *Andropogon virginicus* is here called "Furvinia ellisiana from Pentstemon," although it does not differ materially from the ordinary *Puccinia andropogonis* whose æcial host is normally Pentstemon.

[2] The teliosporic material used in these experiments was on *Andropogon virginicus* and came from two sources: (1) Pedigreed greenhouse material inoculated and grown under control conditions at the greenhouses of the Department of Agriculture at Washington, D. C.; and (2) pedigreed material grown under observation for 3 years at Queen, Va.

TABLE III.—*Teliosporic culture data for Puccinia ellisiana, P. ellisiana from Pentstemon, and P. andropogonis*—Continued

PUCCINIA ANDROPOGONIS—continued

Species inoculated.	Æcial ancestral host.	Source of inoculation material.	Date of inoculation.	Degree of infection.	Pycnia.	Æcia.
			1914.		1914.	1914.
Pentstemon tubiflorus.	Pentstemon laevigatus.	Queen	May 1	No infection		
Do	do	do	May 8	do		
Do	do	do	May 16	do		
Viola papilionacea	do	do	May 1	Sparse	May 10	May 22
Do	do	do	do	No infection		
Do	do	do	May 8	Sparse	May 20	May 30
Do	do	do	May 16	No infection		
Viola palmata	do	do	May 8	Sparse	May 20	May 29
Viola triloba	do	do	do	No infection		
Do	do	do	May 16	do		
Viola hirsutula	do	do	May 8	do		
Viola sororia	do	do	May 16	do		
Viola fimbriatula	do	do	do	do		
Viola sagittata	do	do	May 1	do		
Viola tricolor	do	do	May 8	do		
Do	do	do	May 16	do		
Pentstemon laevigatus.	do	Greenhouse	May 1	Good	May 9	May 22
Viola papilionacea	do	do	do	No infection		
Do	do	do	do	2 sori	May 9	May 22

CULTURE DATA FOR ÆCIAL INOCULATIONS MADE IN 1914 ON GRAMINACEOUS HOSTS [1]

TABLE IV.—*Æcial inoculations with Puccinia ellisiana, P. ellisiana from Pentstemon, and P. andropogonis*

PUCCINIA ELLISIANA

Species inoculated.	Æcial ancestral host.	Date of inoculation.	Degree of infection.	Uredinia.
		1914.		1914.
Andropogon virginicus	Viola sagittata, 1913 Viola sororia, 1914	May 22	Good	June 4
Do	Viola sagittata, 1913 Viola sagittata, 1914	May 25	Leaves old, but infection good.	June 12
Do	Viola sagittata, 1913 Viola sagittata, 1914	May 8	Vigorous	May 25
Do	Viola sagittata, 1913 Viola tricolor (pansy), 1914	do	Fair	Do.
Do	Viola sagittata, 1912 Viola sagittata, 1913 Pentstemon laevigatus, 1914	May 21	Vigorous	June 1
Do	Viola sagittata, 1912 Viola sagittata, 1913 Pentstemon laevigatus, 1914	May 22	do	Do.
Do	Viola sagittata, 1912 Viola sagittata, 1913 Pentstemon laevigatus, 1914	May 25	do	June 3

PUCCINIA ELLISIANA FROM PENTSTEMON

Andropogon virginicus	Viola sagittata, 1912 Pentstemon laevigatus, 1913 Viola tricolor (pansy), 1914	May 12	Poor	May 22
Do	Viola sagitatta, 1912 Pentstemon laevigatus, 1913 Pentstemon laevigatus, 1914	May 22	Vigorous	June 1
Do	Viola sagittata, 1912 Pentstemon laevigatus, 1913 Viola tricolor (pansy), 1914	May 25	Fair	June 10
Do	Viola sagittata, 1912 Pentstemon laevigatus, 1913 Viola palmata, 1914	June 1	do	June 12

[1] All the inoculations here recorded were made with pedigreed material grown under control conditions in the greenhouses of the Department of Agriculture, at Washington, D. C.

TABLE IV.—*Æcial inoculations with Puccinia ellisiana, P. ellisiana from Pentstemon, and P. andropogonis*—Continued

PUCCINIA ANDROPOGONIS

Species inoculated.	Æcial ancestral host.	Date of inoculation.	Degree of infection.	Uredinia.
		1914.		1914.
Andropogon virginicus	Pentstemon laevigatus, 1912.. Pentstemon laevigatus, 1913.. Pentstemon laevigatus, 1914..	May 22	Very vigorous	May 30
Do	Pentstemon laevigatus, 1912.. Pentstemon laevigatus, 1913.. Pentstemon laevigatus, 1914..	June 1	Vigorous	June 15
Do	Pentstemon laevigatus, 1912.. Pentstemon laevigatus, 1913.. Viola papilionacea, 1914	May 22	Good	June 1
Do	Pentstemon laevigatus, 1912.. Pentstemon laevigatus, 1913.. Viola papilionacea, 1914	May 29	.....do.....	June 12

DISCUSSION OF DATA

These tables show that the cycle from a graminaceous host back to a graminaceous host was completed for each species of rust under discussion. They also show that *Puccinia ellisiana* was carried over to Pentstemon, then to Andropogon, then back to both Pentstemon and Viola, and that this was done with pure pedigreed material grown under control conditions at the greenhouses of the Department of Agriculture, Washington, D. C. The cultures made in 1913 with *Puccinia ellisiana* show that the teliosporic stage of this rust is able to infect both Viola (its usual host) and Pentstemon (the common host for *Puccinia andropogonis*). These results were duplicated with pedigreed greenhouse material in the culture experiments made during 1914. The material used in 1914, as previously noted, came from six different sources. The material from five of these sources was pedigreed, and from three was both pedigreed and grown under control conditions. Precaution was taken to prevent contamination of the culture material and cultures throughout all of the experiments made in 1913 and 1914. The culture teliosporic material used was carefully checked under the microscope to further insure its purity. In no case were any signs of contamination found. The characteristic urediniospores for each rust were never found in the culture material of the other.

The author fully realized that on the purity of his teliosporic culture material would depend the validity of his entire series of experiments; hence every effort was made to prevent contamination, and apparently these efforts met with complete success. It was to prevent any chance contamination vitiating the experiments that material was used from so many (six) different sources, as it was very improbable that pedigreed material from widely separated areas would all be contaminated. The teliosporic material of *Puccinia ellisiana* from each of the six sources infected the Pentstemon plants and also infected the various species of

Viola used in each set of inoculations. In many instances the infection of the species of Pentstemon was very abundant and vigorous. This was especially true when the leaves of the *Pentstemon* sp. were at their optimum period of susceptibility.

Puccinia ellisiana did not infect the species of Pentstemon as abundantly as it did certain highly susceptible species of Viola. Nevertheless the infection of *Pentstemon* sp. was so great in many cases that if the material had been contaminated with *Puccinia andropogonis* the thin-walled, echinulate urediniospores characteristic of this rust would easily have been found in the culture material. In not a single instance was there a failure to infect the Pentstemon plants with *Puccinia ellisiana* if the leaves had reached their susceptible period. Two to four pots of species of Pentstemon were used in every set of inoculations, and not only was every plant infected, but in many instances every leaf and even the stem was attacked. In some cases the leaves were so badly infected that they died before all of the æcia opened.

When either "*Puccinia ellisiana* from Pentstemon" or the ordinary *Puccinia andropogonis* was used, the inoculated species of Pentstemon were more vigorously and abundantly infected than when typical *Puccinia ellisiana* material was used. However, when the attempt to carry "*Puccinia ellisiana* from Pentstemon" back to Viola was made, the rust would and did go on to Viola, but with great difficulty.

The data given in the tables do not show this condition fully, for out of nearly 50 pots of *Viola* spp. inoculated only 8 plants were infected. On these 8 plants the infection was very meager. On each of 2 of these plants three leaves were infected, but on each of the other 6 only one leaf was infected and only one sorus to a leaf developed. This is also true of *Puccinia andropogonis*. It will infect certain species of Viola, as the culture table shows, but only very sparingly and then only under the most favorable conditions.

The teliosporic culture material of "*Puccinia ellisiana* from Pentstemon" must be very virile and used in large quantities under the most favorable culture conditions and on a large number of plants of Viola to obtain any infection whatever; and when infection does occur only an occasional leaf out of a large number develops a sorus, while the check plants of Pentstemon used with *Viola* spp. under the same bell jar or in the same inoculating chamber are literally covered with sori. This means that hundreds of viable sporidia were discharged on to the violets and that only an occasional one was able to establish a foothold in the tissues of the violet and finally produce æcia. With less virile teliosporic material and under less favorable culture conditions, inoculations made on species of Viola with either *Puccinia andropogonis* or with "*Puccinia ellisiana* from Pentstemon" would probably fail to infect a single plant. This is exactly what happened in the culture experiments of 1913. No

infection whatever was obtained from *Puccinia andropogonis* when its teliospores were sown on violets.

The *Pentstemon* sp. inoculated with *Puccinia ellisiana* were infected about one-half as heavily as the *Pentstemon* sp. inoculated with *Puccinia andropogonis*, the usual Pentstemon rust, but no failure to infect susceptible species of Pentstemons with either rust occurred in the experiments of 1914.

A test was made with *Puccinia ellisiana* in the open. A small quantity of pedigreed teliosporic material of this rust grown under control conditions at the greenhouse was fastened among the leaves of a bunch of species of Pentstemon growing in open cold frames. The resulting natural infection was exceedingly vigorous and abundant. There were 10 to 15 æcial sori on some of the larger leaves, while every leaf (30) which reached the susceptible period during the viability of the teliospores was infected. This proves conclusively that in nature the ordinary rust on Viola (*Puccinia ellisiana*) is able to infect Pentstemon under the conditions normally obtaining in the field, and that all that is necessary is to have Pentstemon plants intermixed with stools of Andropogon which are infected with *Puccinia ellisiana*.

INCUBATION PERIODS

Table V shows a very variable incubation period for each rust. This variability was to be expected, as it is well known to those mycologists who have done much culture work with rusts that the incubation period varies materially with the environment and host. It increases in length of time as the temperature rises in the greenhouses, and finally infection may cease entirely with extreme heat. But after making due allowances for these factors some interesting facts are seen when each year's cultures are compared. For instance, the incubation period of *Puccinia ellisiana* on violets for 1913 ranged from 13 to 25 days, with an average time of 18 days, while the same rust on Pentstemon in 1913 ranged from 15 to 18 days, with an average of 17 days. This shows a much greater variation in the range of the æcial incubation stage of *Puccinia ellisiana* when on Viola than on Pentstemon, but nearly the same general average. The greater variation in range on species of Viola is probably due to the fact that several species of Viola were used in the inoculation experiments, while only one species of Pentstemon was infected, since the species of Viola used often seems to influence to a limited extent the incubation period. In the cultures of 1914, however, there is about the same amount of variation for *Puccinia ellisiana* on Pentstemon as on Viola. (See Table V.)

TABLE V.—*Incubation period of each rust*

Species of rust.	Incubation of æcia.				Incubation of uredinia.			
	Host inoculated.	Period.			Host inoculated.	Period.		
		Year.	Range.	Average.		Year.	Range.	Average.
			Days.	*Days.*			*Days.*	*Days.*
Puccinia ellisiana.	Viola spp	1912	15 to 24	20	Andropogon	1912	12	12
	do	1913	13 to 25	18	do	1913	17	17
	do	1914	15 to 25	21	do	1914	13 to 18	16
Do	Pentstemon sp.	1913	15 to 18	17	do	1913	17	17
	do	1914	18 to 31	23	do	1914	9 to 11	10
Puccinia ellisiana from Pentstemon.	Viola spp	1914	18 to 29	23	do	1914	10 to 16	13
	Pentstemon sp.	1914	14 to 21	18	do	1914	10	10
Puccinia andropogonis.	Pentstemon sp.	1913	16 to 17	17	do		12 to 13	12.5
	do	1914	17 to 21	19	do		8 to 14	11
	Viola spp	1913				1913		
	do	1914	19 to 22	21	Andropogon	1914	10 to 14	12

When an attempt is made to carry the rust on *Viola* spp. (*Puccinia ellisiana*) back from Pentstemon to Viola, the incubation period is materially lengthened. This is shown in Table V under "*Puccinia ellisiana* from Pentstemon, *Viola* spp., 1914," where the incubation stage ranges from 18 to 29 days, with an average of 23 days, while the same rust on Pentstemon ranges from 14 to 21, with an average of 18 days. The same lengthening of the incubation period also occurs when *Puccinia andropogonis* is carried over to species of Viola. In this case the range is 19 to 22, and the average is 21 days. In general, the incubation period in the change from Viola to Pentstemon is more uniform than in the change from Pentstemon to Viola.

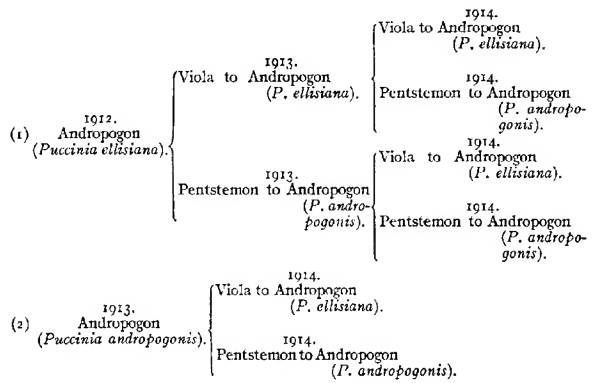
The short incubation period shown in Table V for the urediniospores for 1914 is due to the fact that the blades of Andropogon were very young and tender when inoculated. This condition of the grass was obtained by cutting all the first leaves off and forcing a new lot to develop in the greenhouse. On leaves which had developed in cold frames and then inoculated the incubation period was perceptibly longer.

A comparison of the averages of the incubation periods given in Table V for all the rusts on violets with those on Pentstemon shows that on the violet the general average is 21 days, while on Pentstemon it is 19 days. After making due allowance for the other factors known to influence the incubation period of rusts, this indicates that the æcial host and not the species of rust is the main factor in determining the variability and average length of the incubation period.

MORPHOLOGICAL CHARACTERS

When *Puccinia ellisiana* infects Pentstemon and the resulting æciospores are sown on Andropogon, the urediniospores thus obtained are no longer typical *Puccinia ellisiana* spores, but have the thin echinulate walls characteristic of the ordinary Pentstemon rust, *Puccinia andropogonis*. When the teliosporic material thus obtained is sown on species of Viola and the æciospores from the infected violets are sown on Andropogon, the resulting urediniospores go back to the form typical of the regular Viola rust, *Puccinia ellisiana*. In other words, if the regular rust of Viola passes through Pentstemon, it develops urediniospores of the ordinary Pentstemon rust, *Puccinia andropogonis;* if it is now passed back through *Viola* spp., it develops the urediniospores of the typical Viola rust, *Puccinia ellisiana*. If, on the other hand, *Puccinia andropogonis* is sown on both Viola and Pentstemon, the *Viola* spp. will be very sparingly infected, as previously stated, and the æciospores from this infection when sown on Andropogon produce urediniospores typical of the regular Viola rust, *Puccinia ellisiana*, while if the same teliosporic material is sown on Pentstemon and the æciospores thus obtained are sown on Andropogon, urediniospores typical of the Pentstemon rust are developed. In each case the determining factor as to the characters of the urediniospores is the æcial host. This fact can be more clearly shown by the following diagram:

DIAGRAM SHOWING PLAN OF CROSS-INOCULATIONS WITH PUCCINIA ELLISIANA AND P. ANDROPOGONIS



All of the experiments represented in the above diagram were performed and all of the culture material used, both telial and æcial, was grown under control conditions in the Bureau of Plant Industry greenhouses at Washington, D. C. This diagram represents not only what

the author supposed might occur, but what actually did happen. The dates shown above each host indicate the year in which each set of experiments was performed.

In Table VI are grouped the principal morphological characters of each rust under discussion, so arranged that they can be readily compared.

TABLE VI.—*Morphological characters of Puccinia ellisiana and P. andropogonis*

Stage of growth and morphology.	Puccinia ellisiana on or from Viola.	Puccinia ellisiana on or from Pentstemon.	Puccinia andropogonis on or from Pentstemon.
Æcia:			
Height	Variable, often very long (1 to 2 mm.).	Variable, usually very short (0.5 mm.).	Variable, very short (0.5 mm. or less).
Diameter	275 to 410μ; average for 10, 350μ.	235 to 335μ; average for 10, 260μ.	225 to 315μ; average for 10, 250μ.
Æcial cavity	110 to 165μ; average for 10, 145μ.	115 to 150μ; average for 10, 130μ.	125 to 165μ; average for 10, 135μ.
Peridia, color	Orange, slowly fading to white.	Pale yellow, quickly fading to white.	Pale yellow, quickly fading to white.
Peridia, segments.	Irregular, 4 to 10; not strongly reflexed.	Irregular, 3 to 6, strongly reflexed.	Irregular, 3 to 5, strongly reflexed.
Peridia	Opens tardily	Opens very soon	Opens very soon.
Æciospores:			
Shape	Subglobose	Subglobose	Subglobose.
Markings	Verruculose	Verruculose	Verruculose.
Size, range	12 to 17 by 15 to 18μ	16 to 20 by 18 to 23μ	17 to 21 by 19 to 24μ.
Size, average	For 10 spores, 15 by 17μ	Average for 10 spores, 18 by 21μ.	Average for 10 spores, 19 by 22.5μ.
Urediniospores:			
Shape	Ellipsoid to subglobose	Subglobose to globose	Subglobose to globose.
Walls	Thick, 3 to 5μ; often thicker at apex.	Thin, 2μ, uniform	Thin, 1.5 to 2μ, uniform.
Markings	Verruculose; warts, 15 to 25 across spore.	Spinulose; spinules, 12 to 14 across spore.	Spinulose; spinules, 10 to 12 across spore.
Size, range	16 to 19 by 21 to 23μ	20 to 24 by 20.8 to 25.6μ	21 to 23 by 22.4 to 25.6μ.
Size, average	Average for 10 spores, 17.5 by 19.5μ.	Average for 10 spores, 22.1 by 22.85μ.	Average for 10 spores, 22.3 by 23μ.
Germ pores	4, equatorial	4, equatorial	4, equatorial.
Teliospores:			
Pedicel length	16 to 64μ; average for 10 spores, 46μ.	16 to 57μ; average for 10 spores, 35μ.	16 to 45μ; average for 10 spores, 35μ.
Size, range	16 to 23 by 32 to 45μ	16 to 23 by 28 to 35μ	16 to 24 by 32 to 40μ.
Size, average	Average for 10 spores, 20 by 38.5μ.	Average for 10 spores, 19.8 by 32.4μ.	Average for 10 spores, 20 by 35μ.
Apex	Thickened, 3 to 8μ	Thickened, 2 to 6μ	Thickened, 2 to 5μ.

This table shows some very interesting things. For instance, under "Æcia, height," the characters of *Puccinia ellisiana* when on Pentstemon are practically identical with those of *Puccinia andropogonis;* under "Diameter" the characters are intermediate, but much nearer *Puccinia andropogonis* than *Puccinia ellisiana;* under "Peridia" a decided change is shown in color of peridia, number of segments, and time of opening, from the regular *Puccinia ellisiana* characters to those belonging to *Puccinia andropogonis.*

Under "Æciospores" the shape and markings of the spores of each rust are the same, but in size the æciospores of *Puccinia ellisiana* on Pentstemon are intermediate between the typical *Puccinia ellisiana* on Viola and *Puccinia andropogonis* on Pentstemon.

Under "Urediniospores" all of the fundamental differential characters of the urediniospores of *Puccinia ellisiana* (shape, size, apex, walls, and

markings on the walls of the spores) have been changed by the new æcial host, Pentstemon. The spores have changed from thick to thin walls, from verruculose to spinulose, from ellipsoid to globose, from 16 to 19 by 21 to 23μ to 20 to 24 by 20.8 to 25.6μ, from walls with 15 to 25 warts across the spore to walls with 12 to 14 spinules across. In every instance the Viola rust has changed its characters to those of the ordinary Pentstemon rust. In the teliospores the same trend away from the characters of the typical Viola rust and toward those of the ordinary Pentstemon rust is seen. The characters of the teliospores of "*Puccinia ellisiana* from Pentstemon" are more nearly intermediate between the two regular rusts than are the characters of any of the other stages, but the differences in the characters of the teliospores of the typical *Puccinia ellisiana* and *Puccinia andropogonis* are so slight that one is usually not certain which rust he has unless the urediniospores are present. In other words the characters of each successive stage of *Puccinia ellisiana*, when it has Pentstemon for its æcial host, change to correspond to those of the ordinary Pentstemon rust, *Puccinia andropogonis*.

The large number of successful cultures made on Pentstemon with *Puccinia ellisiana*, the vigor and abundance of the infections obtained, the character of the culture material used, the many sources from which the culture material came, the use of pedigreed culture material grown under control conditions in the greenhouses, the special care taken in the actual culture work to avoid accidental contamination, and the duplication this year of last year's culture results, all prove conclusively that the results obtained in these experiments were not due to accidentally contaminated culture material—that is, to telial material containing viable spores of both rusts—but were due to changes produced by the æcial host through which the rust passed.

The infection of *Viola* spp. by *Puccinia andropogonis* and by "*Puccinia ellisiana* from Pentstemon" further corroborates the results obtained with *Puccinia ellisiana*. These experiments undoubtedly show that the ordinary Pentstemon rust, *Puccinia andropogonis*, can be produced from the Viola rust, *Puccinia ellisiana*, by simply passing Viola rust through Pentstemon as an æcial host. This process is so easy and the infection so vigorous and abundant that it certainly can and does occur in nature, thus originating the ordinary Pentstemon rust. But the reverse process, the passing of the regular Pentstemon rust through the *Viola* spp. and thus back to *Puccinia ellisiana*, is so difficult to accomplish even under the most favorable conditions that it seems probable that such a process would rarely, if ever, occur in nature.

Puccinia ellisiana and *Puccinia andropogonis* are then but different forms of the same species, since both can be produced from the same telial ancestor.

The modification of such profound morphological characters as shape, size, thickness, and markings of the walls of the spores by æcial or other hosts opens a broad and very important field for scientific research. It may prove to be the key to many anomalous conditions in the life history of the Uredinales which hitherto have appeared inexplicable.

The practical importance of these facts in relation to rusts of economic importance, such as those attacking cereals, truck crops, fruit and forest trees, is evident.

SUMMARY

(1) *Puccinia ellisiana* has two widely separated æcial host genera, Viola and Pentstemon.

(2) The infection of Pentstemon by *Puccinia ellisiana* is vigorous and abundant.

(3) The characters of *Puccinia ellisiana* after passing through Pentstemon are entirely changed.

(4) The new characters assumed by *Puccinia ellisiana* correspond in every essential feature to those belonging to the Pentstemon rust, *Puccinia andropogonis*.

(5) The infection of *Viola* spp. by the ordinary Pentstemon rust, *Puccinia andropogonis*, also occurs.

(6) The characters of the rust obtained by inoculating species of Viola with *Puccinia andropogonis* are those of the regular Viola rust, *Puccinia ellisiana*.

(7) The transfer of *Puccinia ellisiana* from Pentstemon back to the Viola is much more difficult than that from the Viola to Pentstemon.

(8) *Puccinia andropogonis* may easily have originated in nature from *Puccinia ellisiana*.

(9) In the case of the rusts under consideration the determining factor as to the characters assumed by the spores is the æcial host.

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ABILITY OF STREPTOCOCCI TO SURVIVE PASTEURIZATION

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INTRODUCTION

In this paper the group name "streptococcus" is used to designate bacteria which are spherical in form and which divide in one axis only, forming chains of from two to many cells. Among the pathogenic streptococci may be mentioned those causing inflammations and suppurations, of which *Streptococcus pyogenes* is an example. Among the nonpathogenic streptococci is a certain species of acid-forming bacterium which has been described as *Streptococcus lacticus*.

It is generally assumed that cocci do not form spores and the vegetative cells would not be expected to withstand Pasteurization. It has been shown, however, in previous publications,[1] that certain strains of lactic-acid bacteria, which would be classified among the streptococci, were able to survive Pasteurization. These strains had a high thermal death point; to destroy one culture in milk it was necessary to heat for 30 minutes at 75.6° C. (168° F.).

Pennington and Walter [2] also found that streptococci in cream survived Pasteurization, but they attributed this to the inefficiency of the Pasteurizing process.

It is evident that certain varieties of streptococci are able to survive Pasteurization, while other varieties are probably always destroyed.

Davis,[3] in a study of the streptococci in milk and their relation to septic sore throat, found that streptococci isolated from cases of sore throat were readily killed by heating at 60° C. (140 °F.) for 30 minutes.

Hamburger [4] found that a streptococcus isolated from a patient having septic sore throat was killed by heating to 62.8° C. (145° F.) for 20 minutes.

These results, together with the protection which proper Pasteurization seems to afford against epidemics of septic sore throat from milk supplies,

[1] Ayers, S. H., and Johnson, W. T., jr. The bacteriology of commercially Pasteurized and raw market milk. U. S. Dept. Agr. Bur. Anim. Indus. Bul. 126, 98 p., 16 fig., 1910.

——— ——— A study of the bacteria which survive pasteurization. U. S. Dept. Agr. Bur. Anim. Indus. Bul. 161, 60 p., 30 fig., 1910.

[2] Pennington, Mary E., and Walter, Georgiana. A bacteriological study of commercial ice cream. *In* N. Y. Med. Jour., v. 86, no. 22, p. 1013–1018, 1907.

[3] Davis, D. J. Bacteriologic study of streptococci in milk in relation to epidemic sore throat. *In* Jour. Amer. Med. Assoc., v. 58, no. 24, p. 1852–1854, 1912.

[4] Hamburger, L. P. The Baltimore epidemic of streptococcus or septic sore throat and its relation to a milk supply. *In* Bul. Johns Hopkins Hosp., v. 24, no. 263, p. 1–11, 8 fig., pl. 1, 1913.

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indicate that the varieties of streptococci associated with or responsible for this disease are among those varieties which have a low thermal death point.

DETERMINATION OF THERMAL DEATH POINT

In these experiments the following method of determining the thermal death point has been used. The streptococci were grown first in plain neutral extract broth for 18 hours and then inoculated by means of a small-bore pipette into litmus-milk tubes. Four drops constituted an inoculation in each milk tube. In making the inoculation care was taken not to have any of the culture touch, or any of the inoculated milk wash up on, the sides of the tube, either during the handling or during the subsequent heating.

The inoculated milk tubes were heated in a large water bath and the temperature of the milk was recorded in a control milk tube by a thermometer placed in the milk. The temperature in the tubes was not allowed to vary over half a degree in either direction. In all the experiments the heating period was 30 minutes at a given temperature. After heating, the tubes of milk were quickly cooled to about 10° C. (50° F.), incubated at 37° C. (98.6° F.), and the reactions recorded. Growth in the tube indicated that the organism was not destroyed at the particular temperature to which the milk had been subjected. In every case the tubes were run in duplicate, and in general both tubes had to show growth before the test was considered positive. The only exception to this was when only one tube showed growth after the highest heating temperature; in such cases one tube was considered a positive reaction, and the organism was recorded as surviving the process.

This method of determining the thermal death point was used in order to render the conditions of heating similar to Pasteurization.

1. THE THERMAL DEATH POINT OF THE CULTURES AS A WHOLE

The thermal death point of 139 cultures [1] of streptococci was studied. These cultures were isolated from cow feces, from the udder and mouth of the cow, and from milk and cream; therefore they represent a wide range of sources of the streptococci commonly found in milk.

The cultures were heated in milk, as previously described, to temperatures ranging from 48.9° C. (120° F.) to 73.9° C. (165° F.). The results given in Table I show the number and percentage of cultures which withstood the different temperatures. Of the total cultures, 138, or 99.28 per cent, survived heating for 30 minutes at 54.5° C. (130° F.). At 57.2° C. (135° F.) 118, or 84.89 per cent, of the cultures survived. At 60° C. (140° F.), the lowest Pasteurizing temperature used commer-

[1] The cultures of streptococci were supplied by Mr. L. A. Rogers, of the Dairy Division, Bureau of Animal Industry.

cially, 89, or 64.03 per cent, withstood the heating. When a temperature of 62.8° C. (145° F.) was used 46, or 33.07 per cent, of the streptococci survived. This temperature of 62.8° C. (145° F.) maintained for 30 minutes is the temperature generally used in the process of Pasteurization. At the higher temperatures the number of cultures which survived grew less as the temperature was increased. At 71.1° C. (160° F.) 3, or 2.58 per cent, of the streptococci survived, while at 73.9° C. (165° F.) all were destroyed.

These results are seen more clearly in figure 1, where they have been plotted. Some of the streptococci were destroyed at 54.5° C. (130° F.) and more at 57.2° C. (135° F.). It is particularly interesting to note that at 60° C. (140° F.) 89 of the cultures survived, while at 62.8° C.

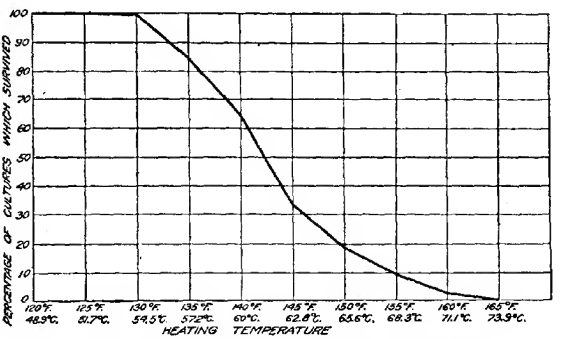

FIG. 1.—Results of heating streptococci for 30 minutes at various temperatures.

(145° F.), a difference of only 2.8° C., or 5° F., only 46 survived; therefore, 51.6 per cent of the streptococci which withstood 60° C. (140° F.) were destroyed at 62.8° C. (145° F.).

It is evident in the consideration of streptococci as a whole that a large percentage are able to survive Pasteurization.

TABLE I.—*Effect of heat on streptococci—all cultures*

Item.	Cultures surviving after 30 minutes heating at—									
	48.9° C. (120° F.).	51.7° C. (125° F.).	54.5° C. (130° F.).	57.2° C. (135° F.).	60° C. (140° F.).	62.8° C. (145° F.).	65.6° C. (150° F.).	68.3° C. (155° F.).	71.1° C. (160° F.).	73.9° C. (165° F.).
Number..	139	139	138	118	89	46	26	13	3	0
Per cent..	100.00	100.00	99.28	84.89	64.03	33.07	18.71	9.35	2.58	0

2. THE THERMAL DEATH POINT OF THE CULTURES CLASSIFIED ACCORDING TO SOURCE

In order to determine whether streptococci from certain sources were more resistant to heating than others, the cultures have been grouped according to their sources. As before stated, the streptococci used in this study were isolated from cow feces, from the mouth and udder of the cow, and from milk and cream.

Table II shows that of the 45 cultures from cow feces, 44, or 97.77 per cent, survived 57.2° C. (135° F.). At 62.8° C. (140° F.) 31, or 68.88 per cent, survived. When heated to 62.8° C. (145° F.), 9 cultures, or 20 per cent, withstood the temperature. At 65.5° C. (150° F.) only

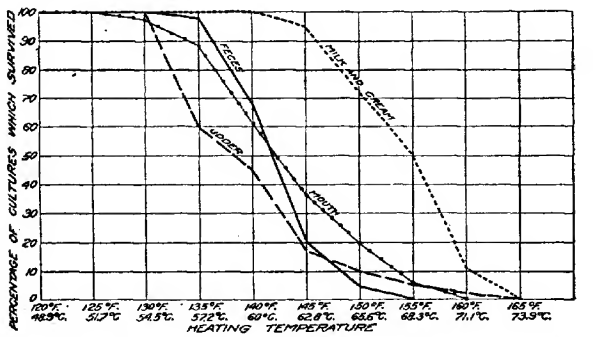

FIG. 2.—Results of heating streptococci (classified according to source) for 30 minutes at various temperatures.

4.44 per cent, survived, while at 68.3° C. (155° F.) all the streptococci were killed.

The cultures from the udder, as a whole, were less heat resistant than those from feces, although a few were able to withstand high temperatures. Of the 40 cultures 60 per cent were able to survive heating to 57.2° C. (135° F.). At 60° C. (140° F.) 45 per cent withstood the heating. At 62.8° C. (145° F.) 17.50 per cent survived. When heated to 71.1° C. (160° F.), 1 culture, or 2.5 per cent, still survived, but all were destroyed at 73.9° C. (165° F.).

In ability to withstand heat the streptococci from the mouth were very similar to those from feces.

The cultures isolated from milk and cream, however, were much more heat resistant than those from the three other sources. At 60° C. (140° F.) 18 cultures, or 100 per cent, survived. When heated at 62.8° C. (145° F.) 17, or 94.44 per cent, still survived. At 65.6° C. (150° F.) 72.22 per cent withstood the heating. Even at a temperature as high as

68.3° C. (155° F.) 9 cultures, or 50 per cent, survived. At 71.1° C. (160° F.) 2 cultures, or 11.11 per cent, survived, but all were destroyed at 73.9° C. (165° F.).

From these results, which are shown diagrammatically in figure 2, it is evident that the streptococci from the udder are, as a rule, less resistant to heat than those from the other sources. Those from the mouth and from the feces have about the same resistance, while streptococci from milk and cream were very much more heat resistant than those from other sources. See Table II.

TABLE II.—*Effect of heat on streptococci—cultures classified according to source*

Source.		Cultures surviving after heating for 30 minutes at—				
		48.9° C. (120° F.).	51.7° C. (125° F.).	54.5° C. (130° F.).	57.2° C. (135° F.).	60° C. (140° F.).
Feces	Number	45	45	45	44	31
	Per cent	100	100	100	97.77	68.88
Udder	Number	40	40	40	24	18
	Per cent	100	100	100	60	45
Mouth	Number	36	36	35	31	22
	Per cent	100	100	97.22	88.88	61.11
Milk and cream	Number	18	18	18	18	18
	Per cent	100	100	100	100	100

Source.		Cultures surviving after heating for 30 minutes at—				
		62.8° C. (145° F.).	65.6° C. (150° F.).	68.3° C. (155° F.).	71.1° C. (160° F.).	73.9° C. (165° F.).
Feces	Number	9	2	0	0	0
	Per cent	20	4.44	0	0	0
Udder	Number	7	4	2	1	0
	Per cent	17.50	10	5	2.50	0
Mouth	Number	13	7	2	0	0
	Per cent	36.11	19.44	5.55	0	0
Milk and cream	Number	17	13	9	2	0
	Per cent	94.44	72.22	50	11.11	0

3. THE THERMAL DEATH POINT OF THE TYPICAL AND ATYPICAL CULTURES

The writers do not consider the chain formation a proper basis on which to divide streptococci into typical and atypical groups. However, grouping is made on this basis in some board-of-health laboratories, and some investigators consider that chain-forming streptococci are associated with infected udders. For this reason the writers believe it of interest to consider the heat resistance of streptococci grouped as typical and atypical on the basis of chain formation.

Among the 139 cultures used in these experiments 22 formed long chains, and were for the purpose of this paper considered typical. The other 117 cultures formed chains of 10 or less, and were considered

atypical. Of the 22 typical streptococci 17 were from udders and 5 from cow feces.

The results in Table III show that the typical streptococci were less resistant to heat than were the atypical. Of the 22 typical cultures 12, or 54.54 per cent, survived 57.2° C. (135° F.). At 60° C. (140° F.) 9 cultures, or 40.91 per cent, withstood the heating. When heated to 62.8° C. (145° F.) 1 culture, or 4.54 per cent, survived, and all were destroyed at 65.6° C. (150° F.). This culture was isolated from cow feces. It is, of course, possible that if a larger number of cultures had been used some would have been found which would have withstood heating to higher temperatures.

Among the atypical cultures a much higher percentage were resistant to the higher temperatures. At 54.5° C. (130° F.) 99.14 per cent survived. When heated to 60° C. (140° F.) 68.37 per cent withstood the temperature. At 62.8° C. (145° F.) 38.46 per cent survived, and at 65.6° C. (150° F.) 22.22 per cent still survived. Even at 71.1° C. (160° F.) 3 cultures, or 2.56 per cent, withstood the heating. All were destroyed at 73.9° C. (165° F.). See Table III.

TABLE III.—*Effect of heat on streptococci—cultures classified as typical and atypical*

Classification of cultures.		Cultures surviving after heating for 30 minutes at—				
		48.9° C. (120° F.).	51.7° C. (125° F.).	54.5° C. (130° F.).	57.2° C. (135° F.).	60° C. (140° F.).
Typical	Number	22	22	22	12	9
	Per cent	100	100	100	54.54	40.91
Atypical	Number	117	117	116	106	80
	Per cent	100	100	99.41	90.59	68.37

Classification of cultures.		Cultures surviving after heating for 30 minutes at—				
		62.8° C. (145° F.).	65.6° C. (150° F.).	68.3° C. (155° F.).	71.1° C. (160° F.).	73.9° C. (165° F.).
Typical	Number	1	0	0	0	0
	Per cent	4.54	0	0	0	0
Atypical	Number	45	26	13	3	0
	Per cent	38.46	22.22	11.11	2.56	0

This marked difference in the heat resistance of typical and atypical streptococci is more clearly shown in figure 3.

Only 1 out of 22 cultures of the typical streptococci survived Pasteurization at 62.8° C. (145° F.) for 30 minutes. As shown in figure 3, the atypical cultures were much more resistant to heat.

From the results of these experiments it is evident that there is a considerable variation in the ability of streptococci to survive Pasteurization, and a general consideration of this ability seems of interest.

RESULTS OBTAINED IN THE EXPERIMENTS

Two classes of streptococci are able to withstand Pasteurizing temperatures, and this is also true of other groups of nonspore-forming bacteria:

Class 1.—Those streptococci which may have a low majority thermal death point but a high absolute thermal death point.

Class 2.—Those streptococci which have a high majority thermal death point.

The terms "high majority thermal death point" and "low majority thermal death point," suggested by Gage and Stoughton,[1] mean the temperature at which the majority of the bacteria are destroyed. In class 1, therefore, the majority thermal death point of the streptococci might be below the Pasteurizing temperature, and they would therefore be destroyed. However, a few bacteria more resistant than the others

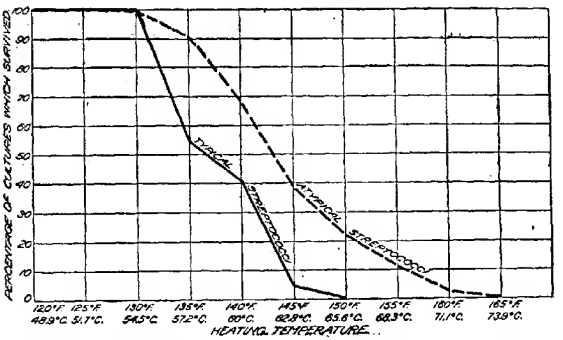

FIG. 3.—Results of heating streptococci (classified as typical and atypical) for 30 minutes at various temperatures.

might survive the Pasteurizing temperature and then continue to develop in the Pasteurized milk. The fact that some of the streptococci which were studied would fall in this class was plainly shown in the experiments of the writers. Often, after a tube of milk containing a culture of streptococci had been heated, the reaction indicating their growth would be shown in 24 hours, while in other cases five or six days' incubation was necessary in order to show an acid reaction, thus indicating growth. In such cases it was evident that only a few bacteria survived the heating. Among this class of streptococci it is quite impossible to say whether a few cells survive high temperatures because of certain resistant qualities peculiar to themselves or whether they are protected in some way in the milk in which they are heated.

[1] Gage, S. de M., and Stoughton, Grace Van E. A study of the laws governing the resistance of Bacillus coli to heat. *In* Technol. Quart., v. 19, no. 1, p. 41–54, 1906.

The second class of streptococci survive Pasteurization because of the fact that their majority thermal death point is above the Pasteurizing temperature. As previously stated in this paper, the writers isolated a lactic-acid streptococcus from Pasteurized milk which required 30 minutes' heating at 75.6° C. (168° F.) to destroy it. During the summer of 1909 some experiments were made to determine the effect of Pasteurization for 30 minutes on this culture at various temperatures. In February, 1914, after having kept this culture by repeated transfers in sterile milk, the experiment was again repeated. As may be seen from Table IV, in the experiments in 1909 there was no reduction of bacteria of this culture when Pasteurized for 30 minutes at 60° C. (140° F.) or 65.6° C. (150° F.), but there was a reduction of 53.07 per cent when heated at 71.1° C. (160° F.) for 30 minutes.

In the repeated experiment with the same culture, about 4½ years later, similar results were obtained. At 60° C. (140° F.) and 65.6° C. (150° F.) there was practically no reduction in the bacterial numbers. The slight difference noted is within the experimental error, as this culture grows with difficulty on solid media. At 71.1° C. (160° F.) there was a reduction of 99.20 per cent.

This organism has a high majority thermal death point, as may be seen from these results, and is able to survive Pasteurization because its majority thermal death point is above the temperature of 62.8° C. (145° F.), the temperature generally used in commercial Pasteurization with the holder process. It is also interesting to note that the ability to resist high temperatures is a permanent characteristic of this organism. (See Table IV.)

TABLE IV.—*The majority thermal death point of a lactic-acid-forming streptococcus*

EXPERIMENT DURING SUMMER OF 1909

Temperature.	Number of bacteria per c. c.		Percentage of reduction.
	Before heating.	After heating.	
60° C. (140° F.)	58,000,000 64,500,000 [a] 61,250,000	63,000,000 51,000,000 [a] 57,250,000	0
65.6° C. (150° F.)	41,000,000	41,700,000	0
71.1° C. (160° F.)	244,000,000 315,000,000 [a] 284,500,000	133,000,000 138,000,000 [a] 135,500,000	.... 53.07

[a] Average.

TABLE IV.—*The majority thermal death point of a lactic-acid forming streptococcus*—Con.

EXPERIMENT DURING WINTER OF 1914

Temperature.	Number of bacteria per c. c.		Percentage of reduction.
	Before heating.	After heating.	
60° C. (140° F.)	1,400,000 1,600,000 [a] 1,500,000	1,040,000 1,180,000 [a] 1,110,000	0
65.6° C. (150° F.)	[a] 1,500,000	1,310,000 1,200,000 [a] 1,250,000	0
71.1° C. (160° F.)	[a] 1,500,000	11,700	99.20

[a] Average.

SUMMARY AND CONCLUSIONS

(1) The thermal death points of 139 cultures of streptococci isolated from cow feces, from the udder and the mouth of the cow, and from milk and cream showed a wide variation when the heating was performed in milk for 30 minutes under conditions similar to Pasteurization.

At 60° C. (140° F.), the lowest Pasteurizing temperature, 89 cultures, or 64.03 per cent, survived; at 62.8° C. (145° F.), the usual temperature for Pasteurizing, 46, or 33.07 per cent, survived; and at 71.1° C. (160° F.) 2.58 per cent of the cultures survived; all were destroyed at 73.9° C. (165° F.).

(2) The streptococci from the udder were, on the whole, less resistant and those from milk and cream more resistant to heat than those from the mouth of the cow and from cow feces. When heated to 60° C. (140° F.) all of the 18 cultures from milk and cream survived; at 62.9° C. (145° F.) 17, or 94.44 per cent, survived; at 68.3° C. (155° F.) 9 cultures, or 50 per cent, withstood the heating process. All the streptococci from milk and cream were destroyed by heating to 73.9° C. (165° F.) for 30 minutes.

(3) Among the 139 cultures of streptococci there were 22 that formed long chains, which, for the purpose of this paper, were considered as typical streptococci. The others were considered atypical. The typical streptococci were much less resistant to heat then were the atypical.

Of the 22 typical streptococci 12, or 54.54 per cent, survived heating for 30 minutes at 57.2° C. (135° F.); at 60° C. (140° F.) 9, or 40.91 per cent, survived; at 62.8° C. (145° F.) only 1 culture, or 4.54 per cent, withstood the heating. All of the typical streptococci were destroyed by heating for 30 minutes at 65.6° C. (150° F.).

The 117 atypical streptococci were more resistant; at 60° C. (140° F.) 68.37 per cent survived; at 62.8° C. (145° F.) 38.46 per cent survived; and at 71.1° C. (160° F.) 2.56 per cent survived; all were destroyed at at 73.9° C. (165° F.).

(4) Two classes of streptococci seem to survive Pasteurization: (*a*) Streptococci which have a low majority thermal death point but among which a few cells are able to survive the Pasteurizing temperature. This ability of a few bacteria to withstand the Pasteurizing temperature may be due to certain resistant characteristics peculiar to a few cells or may be due to some protective influence in the milk. (*b*) Streptococci which have a high majority thermal death point. When such is the case, the bacteria survive because the majority thermal death point is above the temperature used in Pasteurization. This ability to resist destruction by heating is a permanent characteristic of certain strains of streptococci.

(5) The thermal death point determinations in this work were made in milk in such a manner as to represent actual conditions of Pasteurization by the holder process; therefore the results show what may be expected in commercial Pasteurization, and it is evident that some streptococci may survive the process. However, different results might have been obtained if a larger number of cultures had been studied and if other methods and media had been used for determining the thermal death points.

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